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CHAMOSITIC IRON ORE DEPOSITS NEAR TAJMIŠTE, WESTERN MACEDONIA, YUGOSLAVIA

BEN M. PAGE

ABSTRACT

The Tajmište district contains the largest amount of iron ore discovered to date in Western Macedonia. The ore, which is probably Devonian in age, comprises three or more sedimentary beds that are separated from one another by black phyllite. Similar phyllite constitutes several overlying members that alternate with thick Devonian limestones. Triassic limestone and dolomite rest unconformably upon these older rocks.

The ore consists largely of chamosite oolites in a matrix of obscure iron silicate and siderite. Both the oolites and the matrix are partly replaced by diagenetic siderite and tiny crystals of magnetite.

The district is characterized by unusual structure. The sedimentary units dip gently, but are disrupted to an amazing degree by a confusing type of block faulting. Many of the blocks are limestone, where now exposed, and most are bounded by normal faults with inconstant trends and extremely sharp curvature. The block faulting is so unsystematic it may have developed in a shallow thrust plate that moved over an uneven surface. However, this hypothesis is untested.

The prevalent block faulting tends to camouflage important earlier structures. The most prominent exposures are competent, little-deformed limestone that gives no indication of compressional strain. However, low-angle shearing phenomena are widely distributed throughout the phyllite members. Differential movements within the phyllite may explain marked discrepancies in the thickness of enclosed ore, and in the number of ore beds found in closely spaced drillholes.

INTRODUCTION

Background.—The People's Republic of Macedonia, which is one of the six members of the Federative People's Republic of Yugoslavia, is preparing to launch an iron and steel industry. Furnaces are to be erected at Skopje, near which more than fifteen iron ore occurrences are known within a radius of 80 km (Fig. 2). Most of the deposits were not carefully studied until after World War II, but during the past 6 or 7 years a vigorous exploration

program has been in progress. The majority of the deposits are chamositic or related types, and many are apparently small, but two of the most promising areas have reserves measured in millions of tons. These two localities, known as the Tajmište and the Demir Hisar areas, have been developed to a fairly advanced stage in anticipation of mining in the near future. The

FIG. 1. Map of Yugoslavia. Cross marks the Tajmište area.

contemplated metallurgy, and the quantity of ore, are beyond the scope of this paper.

The iron ore deposits near Tajmište [1] are thought to be the largest in Western Macedonia. Although they are sedimentary in origin and were probably at one time rather extensive and continuous laterally, they are now structurally complex and disconnected. Geologic structure is therefore a significant

[1] Approximate pronunciation: Ty'-meesh-teh.

factor in development and eventual mining, especially in view of the fact that most of the mining will have to be done under ground rather than by open pit methods.

Geography of the Tajmište District.—The deposits described here are 4 or 5 km west of the village of Tajmište, Western Macedonia, and are perhaps 30 km from the Albanian border. They may be reached from Kičevo, which is about 30 km by road (16 km in a direct line) to the southeast, and Gostivar, which is approximately 40 km by road to the north. Gostivar is the nearest point on a standard-gauge railroad.

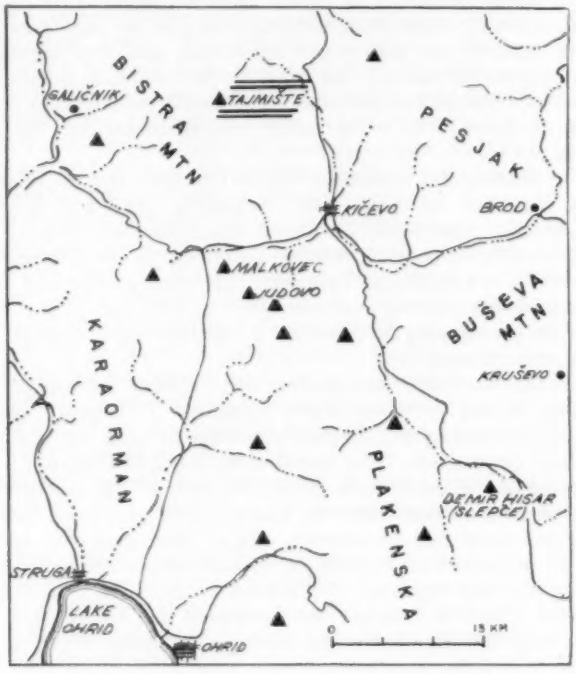


FIG. 2. Location map of chamositic iron ore deposits (shown by black triangles) in Western Macedonia. Modified from M. Dolenc.

The terrain is mountainous, but not insurmountably rugged. The iron ore deposits are on subdued ridges and moderately steep valley sides of the east part of a mountain mass called Bistra Planina, at elevations of 1,500–1,600 m. Winter weather is severe at this altitude, in spite of the moderate latitude.

Previous Studies.—Regional geological summaries and maps of Macedonia include the work of Cvijić (6) and Kossmat (13). Kossmat's publication is a rather remarkable report and map based on data obtained in Macedonia

by German geologists in the period of World War I. A great many other contributions have been made by Yugoslavs, Austrians, and Germans. Geologic maps of Yugoslavia as a whole were prepared by Petković (21) and Mikinčić (18). Mapping on a larger scale was begun in Macedonia during recent years by Izmajlov (10) and several able young geologists under the auspices of N. R. Makedonija Geološka Zavod (the Macedonian Geological Institute).

A number of semi-theoretical regional tectonic syntheses have been made. Most of these are products of Austrian or German geologists, and are strongly flavored by various concepts of Alpine tectonics (e.g., 12, 19, 17). These contributions contain sweeping generalizations not yet supported by enough field work, but they are nonetheless stimulating and they attempt to make order out of apparent chaos. The paper by Medwenitsch incorporates many recent geological discoveries and includes a valuable bibliography of 160 titles; the reader is referred to it for many articles concerning the geology of Macedonia.

Western Macedonian chamositic iron ore deposits and the related geology have been described by Nöth (20), Antonović (1),[2] and Antonović and Nestorovski (2). One deposit, at Demir Hisar, has been expertly studied in particular detail by Dolenc (7), who has also made excellent three-dimensional diagrams of the ore bodies at Tajmište. The stratigraphy and structure of the Rudarski Bazen Kičevo were examined by Ledebur (15). A scholarly report on the petrography and genesis of the chamositic ores of Macedonia was prepared by Cissarz (5).

A great deal has been learned about the Tajmište deposits as a result of the activities of two or three official agencies. The agency primarily responsible for developing and eventually mining the iron ore is the Rudarski Bazen Kičevo (in English, "The Ore-Bearing Basin of Kičevo"). Engineers and geologists of the Bazen have guided the test-drilling, interpreted the results, carried on geological mapping, and compiled geological data necessary for finding and measuring ore reserves. In addition, geologists and engineers of the N. R. Makedonija Geološka Zavod have mapped the geology of areas surrounding the ore deposits. The Zavod za Geološka i Geofizička Istraživanja NRS (Serbian Institute for Geological and Geophysical Investigations) has contributed geophysical surveys, including electrical resistivity studies.

Work Leading to this Report.—The author spent 3½ months in the Tajmište district and other parts of Bistra Planina while employed by the United Nations Technical Assistance Administration in 1955. About two-thirds of this time was devoted to geologic mapping of the Tajmište area, using airphotos as a base. The study was mainly structural.

Acknowledgments.—The writer deeply appreciates the complete cooperation of the Yugoslavs. He is greatly indebted to Ing. Arsen Ristić, Ing. Marjan Dolenc, and other members of the Rudarski Bazen Kičevo, for technical information and frequent assistance. The writer is especially grateful to Ing. Antonije Antonović, of the N. R. Makedonija Geološka Zavod, for

[2] Not seen by the writer, but cited by Medwenitsch (1956).

his constant companionship invaluable geological information, and help of all sorts, cheerfully rendered. Many other persons should be mentioned here, but it is impossible to list them all.

The United Nations Technical Assistance Administration and the Government of the People's Federative Republic of Yugoslavia have kindly made it possible to publish this paper.

ROCK UNITS OF THE TAJMIŠTE AREA

The following descriptions begin with some of the older rock units, and end with the younger, but the various intervening units cannot be treated in exact chronological order. The sequence is known only imperfectly, and perhaps will never be worked out in great detail. Nondistinctive rocks such as gray-black phyllite and gray limestone compose several thick members at different stratigraphic horizons. These nondistinctive units resemble one another closely, and because they have been remarkably disturbed by faulting, their correlation and original stratigraphic positions are obscure. The areal distribution of the rocks is shown on Figure 3.

Paleozoic Phyllite.—Phyllite is one of the most prevalent rock types in the area. Most is gray-black where unweathered, but at the surface it is pale gray to pale tan. All has pronounced slaty cleavage and tends to split into plates or slivers. Nearly all of the phyllite is sedimentary in origin, most of it having once been black shale, presumably marine. Some of it contains layers of fine quartz sand. Fine-grained, laminated phyllitic sandstone locally predominates, but has not been mapped separately. Nearly all of the argillaceous and silty members contain notable amounts of opaque carbonaceous material, and some beds are sprinkled with very fine pyrite. Much phyllite contains small veins of quartz or calcite.

Phyllite of this general character occurs in several places in the original stratigraphic sequence, commonly in thicknesses ranging from 10 to 100 m or more.

One mass of phyllite and interbedded sandy rock, more than 70 m thick, encloses all known iron ore in the Tajmište area. Regrettably, this particular unit, which is of paramount importance, cannot at present be distinguished from other gray-black phyllites in other parts of the stratigraphic sequence. In fact, no one knows how many similar masses of rock exist at various horizons.

Strictly speaking, "phyllite" is not a satisfactory term for these rocks, but it is used for lack of a better designation. The rocks may have undergone more shearing and less recrystallization than the word "phyllite" implies. However the original grains have not been reduced by shearing to an extent that would warrant the term "phyllonite."

On the basis of fossils contained in associated limestones, at least some of the gray-black phyllite is Devonian in age.

Iron Ore Beds (Devonian?).—The iron ore of the Tajmište area occurs as three or more chamositic beds 1–20 m thick, interstratified with gray-black phyllite. The intervening phyllite is 10–60 m thick. The number of ore

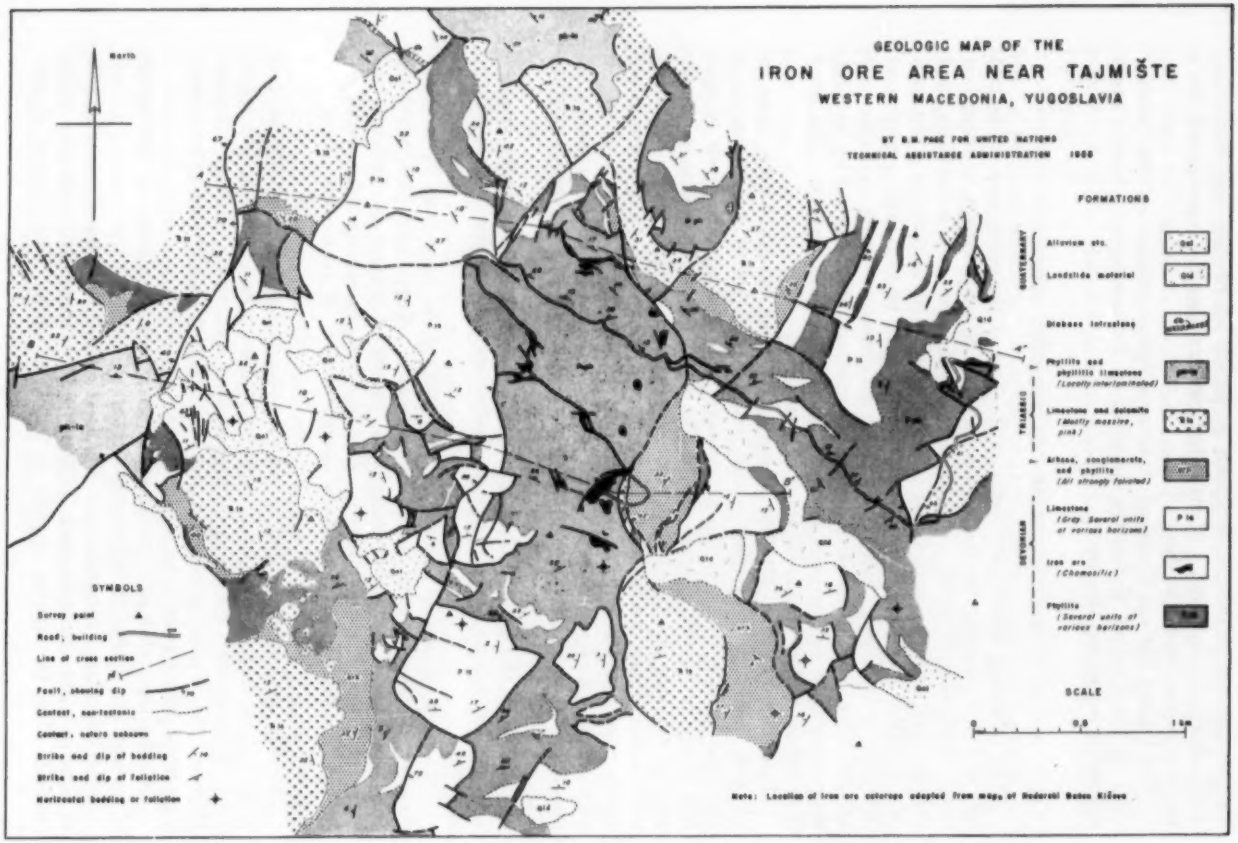


FIG. 3. Geologic map of the iron ore area near Tajmište, Western Macedonia, Yugoslavia.

beds and their thickness vary markedly from place to place within short distances, as indicated in Figure 4. The ore is described in a later section.

Paleozoic Limestone.—Gray limestone is prominent and abundant. Some is gray-white, but some is gray-black where unweathered. Most is more or less recrystallized, yet the texture is not particularly coarse. Faint bedding is preserved in much of the limestone, and locally the rock breaks into thin slabs parallel with pronounced stratification. Crinoid fragments are generally plentiful, but are poorly preserved.

Limestone of this type is not confined to a single stratigraphic horizon. Thin and thick lenses occur within certain gray-black members. Larger bodies of limestone separate some of the gray-black phyllite units, and are 20–300 m or more in thickness. In brief, apparently several sizeable lime-

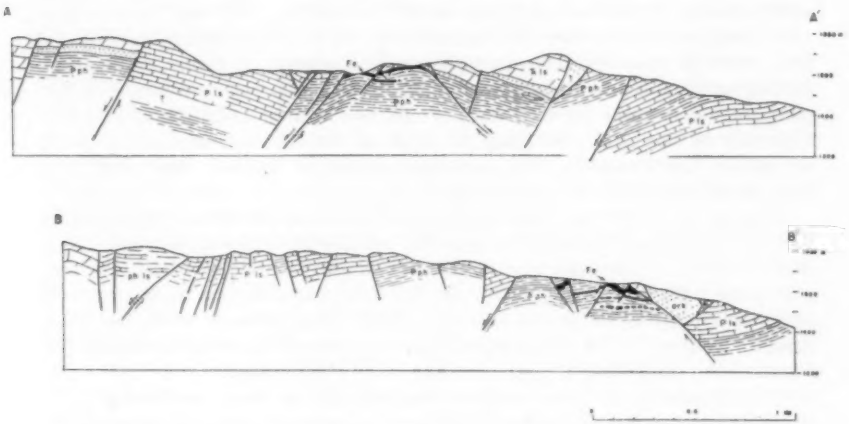


FIG. 4. Cross sections, iron ore area near Tajmište. P ph, phyllite (Devonian?); Fe, iron ore; P ls, limestone (Devonian); ark, arkose, conglomerate, and phyllite; TR ls, limestone and dolomite (Triassic); ph-ls, phyllite and phyllitic limestone. Note: Subsurface iron ore is shown as determined by geologists of Rudarski Bazen Kičevo.

stone masses occur at various stratigraphic levels, and unfortunately they resemble one another very closely. No one knows how many there are, or exactly where they normally belong with reference to the original position of the iron ore beds. Structural evidence indicates that much of the gray limestone lies above the ore beds and their enclosing phyllite. No conclusive evidence has been found near Tajmište to indicate that any thick limestone units exist stratigraphically below the ore. When one observes a crinoid-bearing limestone mass in the Tajmište area, he can assume that gray-black phyllite probably both overlies and underlies the mass in the normal rock sequence.

The age of some of the gray limestone has been established by H. Doreck

Sieverts of Stuttgart.[3] Fossils reported in the immediate vicinity of the ore deposits include the following: *Cyathophyllum* sp., *Heliolites* cf. *porosus, Favosites* sp., *Hexacrinus* cf. *rosthorni, Cupressocrinus crassus,* and *Rhynchonella pugnax*. The most diagnostic of these fossils are said to suggest ages ranging from the upper part of Lower Devonian to mid-Middle Devonian.

A thin marker bed of unusual character occurs within one of the Paleozoic (Devonian?) limestone units. It consists of thin layers and lenticular tablets of gray limestone, 0.2 – 5 cm thick and 0.1–1 m long, embedded in a sand matrix that weathers to a green or greenish yellow color. In places the sand predominates, and more rarely the rock is entirely greenish sandstone. The entire composite bed varies in thickness from 5 m to 0.1 m or less, and it "pinches out" altogether in some localities. The importance of the sandstone-limestone bed stems from its possible uniqueness and thinness. To a certain extent it constitutes a recognizable "marker" or "key bed" in an otherwise monotonous sequence of sedimentary rock. It therefore provides a local index horizon for determining fault dislocations. If future exploratory drilling penetrates this "marker bed" and reaches iron ore far beneath it, the stratigraphic interval between marker and ore will be established, and will thereafter be useful in predicting the depth of the ore beds in some parts of the area. Unfortunately, the sandstone-limestone "marker bed" has only been found in a terrain of limited extent.

Triassic (?) "Arkose" and Associated Rocks.—A sandy, strongly foliated rock lies stratigraphically higher than the bulk of the gray-black phyllite and gray limestone. This rock is greenish gray in most unweathered occurrences, and is medium to coarse-grained. It is somewhat deficient in quartz, and contains opaque white grains that may have been feldspar, so it has been termed "arkose." The constituent particles, except quartz, are markedly flattened and somewhat elongated parallel with the foliation.

The "arkose" is, in some localities, accompanied by fine to medium grained conglomerate of similar character. The conglomerate is greenish to violet, as a rule, and is deformed and foliated. Most of the pebbles are wafer-thin; the majority are green, white, or maroon phyllite. Gray-black phyllite detritus is not conspicuous, and pebbles of Paleozoic limestone are scarce or wanting, although these might be logically expected. Quartz grains are subordinate.

Green or violet phyllitic beds commonly occur with the "arkose" and conglomerate, either beneath or interbedded with them. It has been necessary to map the "arkose," conglomerate, and associated phyllite together as a composite unit.

This unit varies markedly in thickness, ranging from almost nothing to perhaps 180 m or more. The age and normal field relations are imperfectly known, but structural evidence and areal distribution at least prove that that "arkose" and associated rocks overlie the gray-black phyllite and the gray limestones. The rocks beneath the "arkose" are Paleozoic, some being as old as Devonian. The overlying pink limestone is Triassic. This leaves a great deal of geologic time to be accounted for, implying the existence of an unconformity either above or below the "arkose"-conglomerate-phyllite forma-

[3] M. Dolenc, oral communication, 1955.

tion. The lower boundary of the latter appears to be gradational at a locality several kilometers south of Tajmište, on the trail from Greznitsa to Lazaropole, and the plausibility of this impression is strengthened by the lack of gray-black phyllite detritus in the "arkose" and associated rocks. On the other hand, about 1–2 km southwest of the mapped area, there is an exposure of a sharp contact between the "arkose" and underlying gray-black phyllite. One or two pebbles of the latter were found in the "arkose." Thus, there are arguments both for and against the existence of an unconformity beneath the "arkose," and the age of the formation is accordingly unsettled, being either Paleozoic or Triassic. The character of the upper boundary of the formation is also debatable, and will be discussed below.

Triassic Limestone and Dolomite.—Triassic carbonate rocks are prevalent and prominent, forming extensive rugged elevated tracts devoid of soil and typically marked by cliffs. Some of the rock is dolomitic, and much is massive. The color is characteristically pink or white, unlike most of the Paleozoic limestones; only rarely is it gray. The maximum thickness is unknown, but apparent thicknesses of 200 m or more may be measured. The Triassic age of the rock was determined prior to the writer's work, from fossils. This was an important contribution, as all the limestone in the Tajmište area had previously been lumped together. The discovery that some limestone is Devonian and some is Triassic made it possible to discern many faults that might otherwise have been unnoticed.

Some geologists believe that the Triassic rocks have been thrust over the underlying rocks (17, p. 446). However, in one or two places the writer found a non-tectonic boundary between the pink Triassic dolomite-and-limestone and the rocks beneath. About 400–450 m north of the mine headquarters buildings, a small exposure was discovered in which the pink Triassic rocks rest upon arkose or quartzite with no intervening fault. Pebbles of the quartzite are incorporated in the limestone. In another locality, near the west end of Cross Section A–A′ (Fig. 4), the pink limestone appears to rest concordantly upon arkose and phyllite. These relations are important with reference to structural interpretation.

The Triassic carbonate rocks are generally correlated with the Han Bulog rocks. The latter are reddish limestones of Bosnia, Hercegovina, and Dalmatia; they belong to the Anisian stage of the Middle Triassic, and are said to be equivalent in age to the Muschelkalk of Germany and the Hallstatt limestone of the Eastern Alps. According to Medwenitsch (17, p. 445–446), the physical resemblance of the pink limestone at Tajmište to the Han Bulog rocks is strengthened by the discovery of ammonites of two characteristic species, *Balatonites semilaevis* Hauer and *Gymnites* cf. *bosnensis* Hauer immediately adjacent to the mine area. The writer observed pelecypod fragments and poorly preserved ammonites in the vicinity of the discovery site.

Triassic (?) Phyllite and Phyllitic Limestone.—An extensive formation north and west of the exposures of iron ore is here called "phyllite and phyllitic limestone." It is broadly distributed in high, grass-covered uplands stretching far beyond the mapped area of Figure 3. It shows a platy structure throughout. Parts of the formation are phyllite, parts are foliated lime-

stone, and parts are alternating layers of phyllite and limestone 0.1–5.0 cm thick. In several localities thin layers of limestone alternate with wavy laminae or films of green chlorite.

This composite formation is unlike the rocks in the central part of the mapped area, and obviously does not belong in the immediate proximity of the iron ore beds. It must normally be far above the ore, or far below. The writer believes it belongs above the ore, and in fact above the pink Triassic dolomite and limestone. A clue is found 2,150 m northwest of the mine headquarters buildings; here pink Triassic limestone and dolomite grades upward into thin-layered limestone and phyllite probably belonging to the formation here described. Wherever this formation occurs at the surface, there is no likelihood of finding accessible iron ore above or below it.

Minor Rocks and Superficial Materials.—A few dikes and sills of diabase were noted in the Tajmište area, but they have no importance with respect to the iron ore deposits. Landslide material and thick mantles of soil have been mapped in Figure 3 where bedrock is concealed in areas of appreciable magnitude. Alluvium and other superficial debris have also been mapped.

IRON ORE

Field Relations.—Iron ore composes three or four beds in one of the Paleozoic phyllite members. The ore beds range in apparent thickness from a few cm to 20 m, and the intervening phyllite ranges from 10 to 60 m. The number of ore beds, as well as their thickness, varies markedly within a distance of, say, 100 m. This variation may be largely the result of tectonic disturbance, as indicated in the section headed "Geologic Structure." Similar ores of comparable age are known at many widely scattered localities in Western Macedonia, so it seems probable that the ore beds were originally extensive and collectively rather persistent, although they may never have been uniform or individually continuous. At present the ore-bearing areas such as Tajmište are bounded by faults, and are separated from other ore-bearing areas by broad tracts of seemingly barren rock, measured in tens of square kilometers. Some of these tracts may contain ore at depth; on the other hand, perhaps no ore was deposited in certain parts of the region, or it may have been removed by erosion or tectonic movements.

At Tajmište, the iron ore discovered up to mid-1955 is in an uplifted, deeply eroded fault block subdivided by minor faults. The ore beds are limited by faults and are repeatedly offset. An intensive drilling program has been necessary to outline the various segments of ore and to determine the depths and thicknesses of these segments. Exploratory holes are drilled on a 70 m grid, and if warranted, intervening holes are then drilled, so the final spacing is commonly 35 m. Exploratory underground workings have also been made. Drill cores and underground exposures show that some of the ore is bounded by sharp contacts with underlying and overlying phyllite; on the other hand, some of the ore grades into iron-rich phyllite which in turn grades into barren phyllite.

No volcanic rocks have been found in association with the iron-bearing

beds at Tajmište. However, at Demir Hisar, near Slepče (approximately 47 km SE of Tajmište), comparable sedimentary ores and enclosing Paleozoic phyllite are apparently underlain by altered diabasic flows and tuffs more than 100 m thick (7).

Petrology.—The iron ore weathers rusty brown, but where unweathered is inconspicuous, being nearly black like the associated phyllite. It is, however, somewhat more massive, blocky, heavier, and harder than the phyllite. Its minerals and texture are best seen in thin section. The petrography and origin of the ore have been treated in detail by Cissarz (5), so the following observations may be supplemented by reference to his work.

The typical ore is oolitic (Fig. 5), although this is not always noticeable to the naked eye, and it consists mainly of iron silicates and carbonate. The oolites are not evenly distributed, and the matrix is not uniform; moreover, these inequalities are not expressed in a definite stratification. Instead, the oolite-rich and oolite-poor areas generally take the form of irregular streaks, swirling wisps, and cloud-like patches with indistinct boundaries. In addition to true oolites, the ore contains pellets and rounded bodies that may or may not have been oolites prior to diagenesis.

The matrix between oolites contains varying proportions of muddy-looking isotropic iron silicate, fine-grained cloudy siderite, clear siderite, green chloritic material, carbonaceous (?) matter, and tiny crystals of magnetite.

The oolites are 0.1–1.5 mm long, and are composed largely of green chamosite (composition approximately $3FeO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 3H_2O$). The chamosite is exceedingly fine grained, and the minute flaky crystals are concentrically oriented. Therefore the oolites, when viewed in thin section with crossed nicols, show the well-known extinction cross that remains stationary as the microscope stage is rotated. Not all oolites are entirely chamosite. Some have been partly replaced by siderite, and many of the concentric shells are black with tiny magnetite crystals and probably carbonaceous matter, these opaque substances being concentrated selectively in certain of the onion-like layers.

Most of the oolites have nuclei quite different from the concentric layers. Perhaps those which do not show nuclei in thin section are cut off-center. Some nuclei are siderite rhombs. Others are angular, polycrystalline aggregates of apatite (?) or colorless iron silicate (?) with low birefringence. Some nuclei are rounded, green, amorphous looking, isotropic iron silicate; others resemble glauconite. A very few nuclei are magnetite.

Dense portions of the ore, here termed "concretionary," are visible in thin section (Fig. 6). These are distinctly to vaguely bounded. They contain oolites that are sparser, less altered, and less deformed than those in the rest of the ore. The concretionary parts obviously became lithified relatively early, thereby protecting the enclosed material from changes that affected the remainder of the ore. The protected oolites are chamosite, and the matrix (which is considered to be an original sediment) is a fine-grained, murky aggregate of isotropic iron silicate (?) and minute, cloudy siderite (?) grains.

Outside the dense concretionary portions, most of the oolites and matrix are partly replaced by relatively coarse siderite and by fine-grained magnetite.

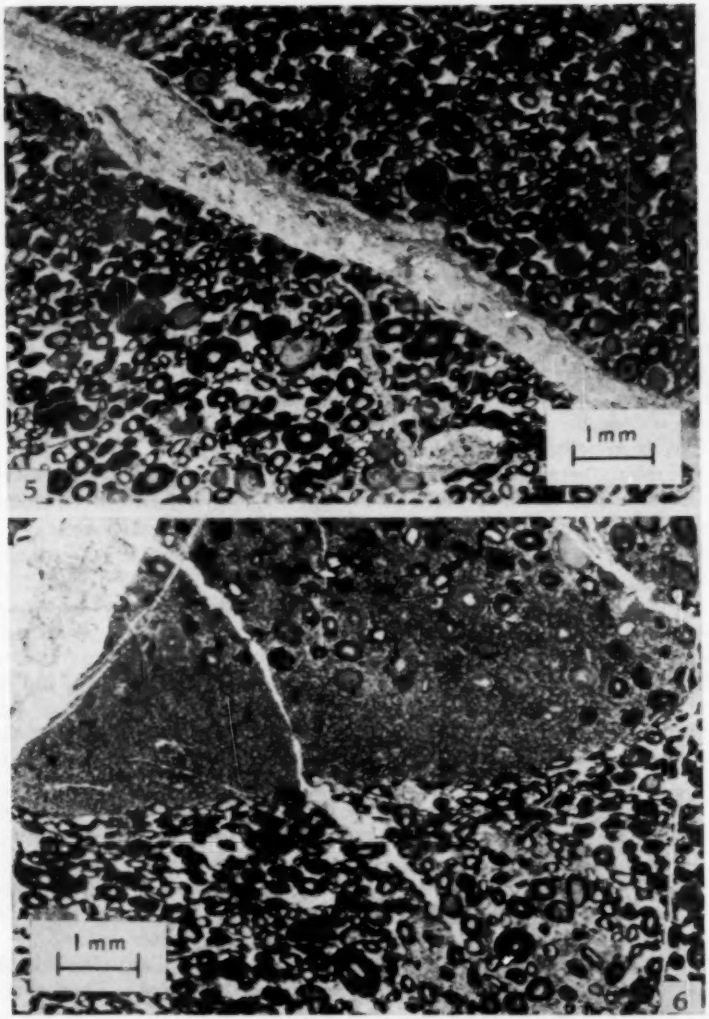


FIG. 5. Iron ore. Gray oolites are chamosite; black oolites and ooids are largely replaced by magnetite. Matrix is siderite and green iron silicate. Veinlets are carbonate, in part. (Photomicrograph, ordinary light.)

FIG. 6. Iron ore. Concretionary parts, upper half and lower right, are carbonate-rich and show fewer oolites than remainder of view; the included oolites are less deformed and less replaced than those outside the concretionary parts. Black, deformed oolites, such as those just below center, are largely replaced by magnetite. (Photomicrograph, ordinary light.)

Cissarz (5) noted subsequent "garlands" of clear iron silicate enveloping oolites that had been partly altered to magnetite. Later pyrite is visible in some ore specimens, replacing both matrix and oolites.

Typically, but not universally, oolites and ooids outside the concretionary areas are ellipsoidal. The ratio of long axes to least axes is commonly about 1.5 : 1, and is locally 2.5 : 1. The ellipsicity is partly a secondary effect, as proved by the preservation of near-spherical oolites in well cemented portions of the ore. Bedding is not definitely discernible, so the relation between the orientation of bedding and ellipsoidal oolites is not clear. However, where streaky textural variations occur, the oolites generally are obliquely oriented with respect to the streaks. Probably this resulted from deformation involving solid flow. The ore beds have been further affected by fracturing that was followed by the formation of calcite veinlets. The latter were themselves fractured and offset. Altogether there are three or four successive sets of calcite veinlets. Therefore considerable movement has occurred within the ore at various times, as would be suspected from the structures of the associated phyllite.

Origin.—The chamositic ore is assumed to have been a marine sediment, judging from the associated strata. The ore-forming sediment accumulated by chemical precipitation in water that must have been quiet, inasmuch as clastic detritus is scanty. The oolites are not well sorted; some of the largest have 50 times the volume of their neighbors. Lack of sorting and lack of stratiform distribution could mean that wave and current action were feeble; or, the oolites may have grown *within* as well as *upon* the freshly deposited matrix material.

The composition of the concretionary portions of ore, which are best preserved, supports the conclusions of Cissarz (5). He believes that the primary deposit was mostly iron silicate gel and chamosite, the latter forming oolites. The writer thinks there was also some original siderite, which is present as fine, cloudy material in the concretionary matrix.

Relatively coarse siderite and all the magnetite are clearly secondary in the sense that they replace the original minerals. However, they are probably both diagenetic rather than products of late alteration or metamorphism. Cissarz (5) points out that both minerals occur in oolites that are enclosed in envelopes of clear iron silicate.

The mineral assemblage would indicate, according to the scheme of Krumbein and Garrels (14), an environment in which the pH was 7.0 to 7.8 ±, and the Eh was 0.0 to − 0.2 ±. Carbonaceous (organic) matter and the persistence of ferrous iron suggest a reducing environment, which must have been dependent upon lack of effective wave action and lack of descending currents. Low-temperature authigenic magnetite has been recognized elsewhere in oolitic iron ores (9), and in the banded iron-formation of the Lake Superior district (11). It is considered compatible with the conditions postulated above.

The source of the iron is unknown. Basic volcanic rocks are reported near the Demir Hisar chamositic deposits, 47 km from Tajmište. Cissarz (5) suggests that submarine springs or exhalations of volcanic origin may have contributed Fe, SiO_2, and CO_2 to the sea water during the deposition

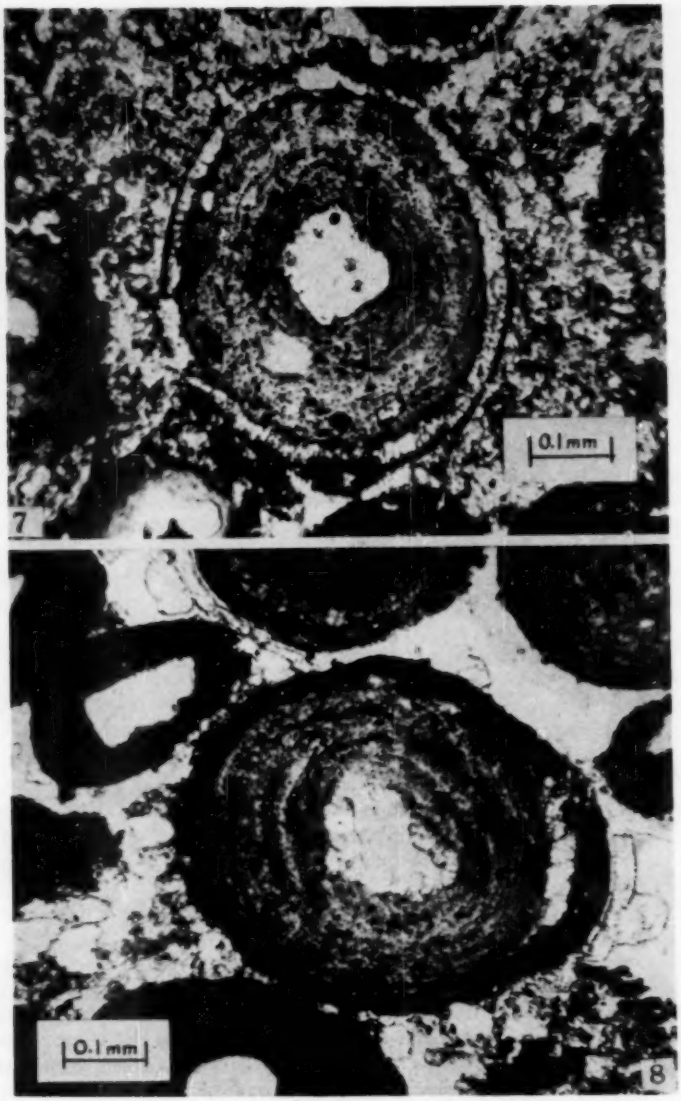


FIG. 7. Chamosite oolite with carbonate (siderite?) nucleus and rind. Surrounding matrix is carbonate (siderite?), and isotropic iron silicate. Magnetite occurs as disseminated grains in large oolite, and has replaced smaller oolites, lower right. (Photomicrograph, ordinary light.)

FIG. 8. Chamosite oolite with nucleus of isotropic green iron silicate. Magnetite has replaced rind of large oolite, much of adjacent oolites, and part of matrix, lower right. Light parts of matrix are green iron silicate and relatively coarse secondary siderite. (Photomicrograph, ordinary light.)

of some or all of the Western Macedonian deposits, but recognizes that local evidence is lacking at Tajmište. He envisages geosynclinal conditions.

Discussions of the origin of iron silicate and carbonate ores elsewhere include noteworthy papers by Hayes (8), Berz (3), Lindgren (16), Borchert (4), and James (11). These contain references to many others.

Chemical Characteristics.—The iron content of the ore is said to range up to 39.7 percent, but the substantial reserves are probably 32–37% Fe. The lower limit is arbitrary, inasmuch as some of the chamositic phyllite contains 25% Fe. If the ore were pure chamosite, the iron content would approximate 33 percent. Siderite, magnetite, and supergene limonite account for the higher values. One of the consequences of the abundance of chamosite is a high percentage of Al_2O_3 (probably 11–18%) and SiO_2 (10–16%). Apparently the environment of sedimentation that favored the persistence of iron in the ferrous state also favored the preservation of organic products and the deposition of phosphates. The ore is reported to contain 0.1–0.3% S (from secondary pyrite and marcasite), and 0.5–0.9% P (presumably from sedimentary apatite).

Age.—The age of the Tajmište ores is probably Lower or Middle Devonian. This supposition is based partly on evidence in the Tajmište area itself, and partly on evidence near Judovo, 18 km to the south. At Tajmište the oldest dated rocks are fossiliferous limestones considered to be upper Lower Devonian or lower Middle Devonian in age. These have not been found in a continuous stratigraphic section, but on structural grounds they are thought to lie stratigraphically above the chamositic beds. At Judovo, limestones with better preserved fossils are found in the vicinity of sedimentary iron ores comparable to those of Tajmište. Several limestone members (with intervening phyllite) are stratigraphically above the ore, and one similar member is beneath the ore. The limestones above the iron rich beds have yielded crinoids, brachiopods, corals, and goniatites; most of these are said to be Middle Devonian, and a few may possibly be Upper Devonian in age. The limestone beneath the ore bears only crinoid fragments, but is tentatively thought to be Lower Devonian. The indicated Devonian age of the iron ore is interesting in view of the occurrence of early to middle Paleozoic oolitic iron ores in Central Europe and in North America.

GEOLOGIC STRUCTURE

The Tajmište district is characterized by unusual block faulting of amazing complexity. This dominates the scene, and tends to camouflage the effects of earlier horizontal movements. The deception is strengthened by the prevalence of gentle dips, apparent lack of overturned beds, and the structural simplicity of the best exposed blocks (chiefly competent limestone). However, strong deformation certainly preceded the block faulting. The movement was concentrated in the phyllite members, which at present are topographically recessive and poorly exposed.

Altogether, the structure of the district reflects three types of deformation: 1. Low-angle movements. 2. Broad, gentle folding. 3. Block faulting. Possibly the last two are closely related to the end stages of the first.

Effects of Low-angle Movements.—Some of the rocks, particularly the phyllites, show structures indicating differential transport with a large horizontal component. The expression "low-angle movement" is used to distinguish this from the more conspicuous block faulting that occurred later. For present purposes, "low-angle" is a relative term, referring to movements that ranged from horizontal to an inclination possibly as great as 45 degrees. These movements were not confined to faults, but were distributed through the clastic rocks, locally affecting almost every portion.

The phyllite commonly shows one or several *s*-planes that have either influenced, or resulted from, penetrative deformation. For example, in Figure 9 some slip has presumably taken place along the bedding (S_1), facilitating the introduction of quartz and calcite veinlets. The veinlets show microthrusts and drag folds caused by renewed movement. Slightly later shears of microscopic magnitude define S_2 at an acute angle to the bedding (upper part of figure). Incipient oblique cleavage (S_3) has developed in association with myriads of microscopic wrinkles, a familiar but puzzling phenomenon.

Slip along the foliation plane in phyllite is megascopically evidenced by the shearing off of a few sandy beds at an acute angle. It is also shown by closely spaced offsets in veinlets that lie at an angle to the foliation. Many of the offsets are only 1 to 5 mm in magnitude, but they are so numerous they collectively represent a substantial amount of strain.

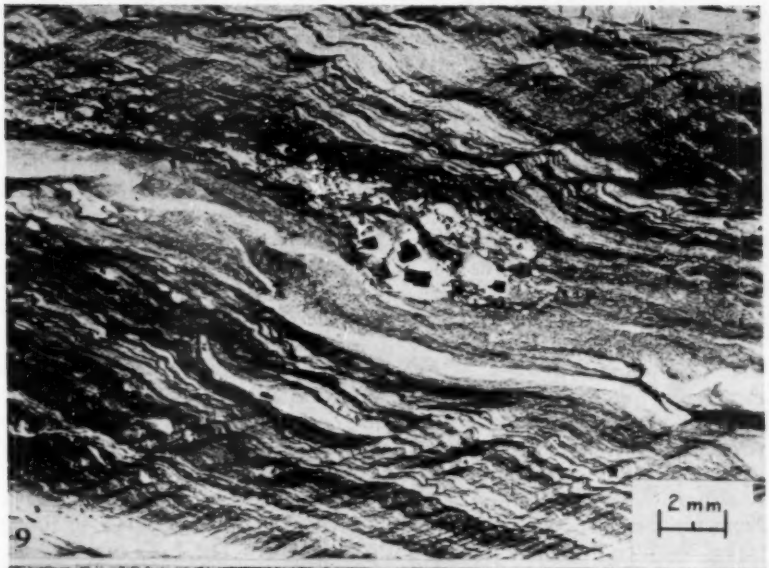
Mylonitization of limited extent has accompanied some of the penetrative shearing (Fig. 10). Mylonite is not readily discernible in surface exposures, but is seen in rock cores from exploratory drillholes in phyllite.

Small thrust faults were noted in the Tajmište district, but those seen in the mapped area have displacements of less than 10 m. It is possible, of course, that other thrusts were not detected or were mistaken for normal faults.

Tiny, closely spaced wrinkles .05–0.5 mm high are prevalent on some of the foliation surfaces of the phyllite. Commonly two sets of wrinkles are seen, one set trending nearly east-west, and the other lying nearly at right angles to the first. Somewhat larger folds, generally with an amplitude of .01–1 m, are found in a few places. Some are recumbent. Examples of these, with attenuated and sheared-off limbs, are visible in roadcuts near the Tajmište mine buildings, where small quartz veins serve as indices of deformation.

The low-angle deformation is probably of practical importance. Very likely the pinching and swelling of the ore, and locally its discontinuity, have been partly caused by the differential movement within the enveloping phyllite, although this remains to be demonstrated when the ore is more fully exposed to view. The expected effects are indicated by the structural behavior of sandy layers enclosed in phyllite. Locally, these relatively competent materials have been strewn out in the form of disconnected lenticular segments, somewhat in the manner of boudinage. The iron ore is known to vary markedly as to thickness and number of beds, and this may indicate that it, too, is separated into lenticular segments.

The shearing-out of phyllite and associated rock layers is not uniformly



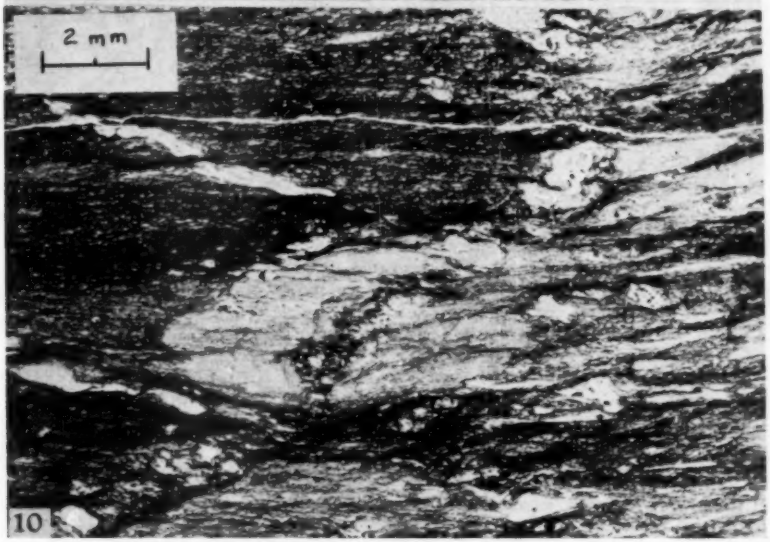


FIG. 9. Phyllite above ore horizon, showing results of penetrative movement. S_1 (bedding, slip planes, and veinlets) is diagonal from upper left to lower right. S_2 (shear planes) is parallel with upper edge of photo. S_3 (incipient oblique cleavage) trends from upper right to lower left. Secondary pyrite in quartz, center. (Photomicrograph, ordinary light.)

FIG. 10. Phyllite above ore horizon, showing penetrative shearing and mylonitization. Note probable vestiges of bedding trending from upper right to lower left. (Photomicrograph, ordinary light.)

distributed. Consequently, it is not surprising that beds in a given drillhole may be missing in a nearby drillhole. This structural circumstance will make correlation difficult even if ways of recognizing the various parts of the phyllite units are discovered.

Neither the Paleozoic limestones nor the Triassic carbonate rocks show pronounced shearing or flowage. Some Paleozoic limestone is slightly fissile, but most is massive and the contained fossils (e.g., crinoid segments) show little distortion. The Triassic limestone and dolomite is almost entirely massive, and the few fossils are not markedly deformed. Evidently the carbonate rocks escaped the penetrative deformation of the phyllite. Probably these massive units played the role of competent elements, which were bodily transported during tectonic disturbances. The competent masses transmitted stresses to the weaker phyllite members, which readily crumpled and sheared.

Probably the low-angle movements took place during a long history of successive tectonic episodes. Presumably all were post-Devonian, and at least some were post-Triassic. The direction of movement varied. One prevalent set of wrinkles and small offsets consistently suggests that the upper part of the crust moved southward relative to deeper parts. However, other (later?) structures indicate a nearly east-west movement.

Broad, Gentle Folding.—The rock formations are not folded tightly, but commonly dip 5 to 25 degrees. The inclination is ascribed partly to tilting during block faulting, and partly to broad folding. The folds are not continuous, because of subsequent faulting, but apparently their original trend was north-northeast. The vestige of a faulted syncline may be seen in the righthand portions of Cross Sections A–A′ and B–B′ (Fig. 4). This syncline meets the east edge of the developed ore-bearing area near the center of the map, Figure 3; when followed southward it becomes vague due to flattening of the west limb. Other indistinct folds may be discerned, but they cannot be traced very far.

Question of Major Thrust Faults.—There has been persistent disagreement as to possible large-scale thrust faulting in the Tajmište district, and future development of iron ore may be affected by the eventual interpretation. The writer examined possible large thrusts near the ore deposits, and concluded that they are *not* thrusts. However, he is strongly of the opinion that the entire area may be underlain by a thrust fault that does not crop out in the terrain that was studied.

Circumstances that might lead one to expect thrust faults in the district are: 1) The prevalence of structures described above under the heading, "Effects of low-angle movements." 2) The chaotic block faulting, discussed below. 3) The presence of one or two thrusts of modest proportions observed on Mount Bistra between Tajmište and Tresonče. 4) Indications of overturning and faulting near the Albanian border, 20–30 km away. 5) The geographic situation of Tajmište with respect to the Dinarides mountain chain.

Despite these suggestive circumstances, the writer did not see any large scale thrusts in the area mapped, or in the region immediately to the west. A predecessor, von Ledebur (15, p. 31), concluded that the many limestone masses of Mount Bistra have been kneaded together and thrust in "Schuppen"

fashion. Medwenitsch (17, p. 466) believes he saw Triassic limestone near Tajmište resting with clear overthrust relation upon phyllite of the Devonian chamosite-bearing series, and shows in a diagrammatic regional map (17, facing p. 400) what appears to be a "Schuppe." The writer interprets such exposures near Tajmište as unconformable depositional relationships (Fig. 4).

In summary, thrusts of large proportions probably exist near Tajmište, and the writer suspects that a thrust underlies the mining area at depth, but none has been conclusively demonstrated.

Block Faulting.—The most conspicuous structural character of the Tajmište region is the result of block faulting (Figs. 3, 4). The region is a remarkable mosaic of slightly tilted blocks, which are exceptional in their profusion and irregularity. The faults bounding the blocks are chiefly normal or nearly vertical. A few are relatively long and straight, but most are short and notably curved, angular, or crooked. Some of the blocks have rather straight margins, as viewed in plan, but others are ragged.

The faults that were mapped are only 20–500 m apart, and if all smaller displacements were plotted, there would be no spacing greater than 100 m. Where accurately determined, the dips generally range from 40 to 80 degrees. Some dips vary greatly along the strike, and presumably also vary with depth. Apparent dip-slip displacements exceeding 400 m may be measured, and undoubtedly there are larger displacements not yet ascertained.

Many of the fault blocks are limestone at the ground surface, and these blocks are topographically prominent. Some are side by side with phyllite blocks, and some are in contact with other blocks of limestone. One of the peculiar characteristics of the district is the presence of narrow slivers of phyllite separating some of the limestone blocks. At the ground surface, these phyllite slivers make grass-covered "corridors" between rugged, bare, limestone hills.

There are two outstanding trends of the more extensive faults: north-northeast and north-northwest. However, taking into account the lesser faults and deviations of the more extensive ones, there is an infinite number of trends. It is not practicable to divide the faults into various age groups based on average strike. Some east-west faults terminate against north-south faults, but the opposite relationship is also noted. Apparently many of the faults of various trends are approximately contemporaneous. Incidentally, none are recent enough to directly shape the present topography.

The extremely unsystematic block faulting cannot be explained in terms of elementary mechanics. Clearly, the erratic strain has not resulted from homogeneous stress in a homogeneous medium. A possible explanation is that the irregularly block-faulted terrain may be a thrust plate which moved over an uneven surface to which it adjusted by vertical dislocations. However, the thrust is purely hypothetical.

The economic importance of the block faulting is very great. All of the ore that had been developed by drilling and tunneling at the time of the writer's visit is an integral part of a large block that is completely bounded by faults (Figs. 3, 4). The developed block is composite, in the sense that it is broken into minor blocks, and accordingly the ore is dislocated every few

meters. Erosion has removed a great deal of rock from the upper part of this composite block, exposing the ore beds in places and making them accessible to drilling in other places. Ore has not been found in any of the nearby blocks, but probably it exists at depth well beyond the tract in which it is now recognized.

Resumé of Tectonics.—Low-angle differential movements took place after the Devonian period, probably during several successive episodes. Much of the deformation was post-Middle Triassic. These movements chiefly affected the phyllite units, some of which enclose the ore.

The ore itself resisted the deformation somewhat, but discrepancies in thickness and continuity of ore beds are believed to have resulted partly from this action. Limestone and dolomite formations escaped penetrative effects of the low-angle movement. It is likely that these rocks behaved as rigid members that were pushed along laterally, transmitting the disturbance to the phyllite above or below.

During or after the low-angle deformation, gentle folding occurred.

Block faulting took place along normal or vertical faults. This produced a confused array of tilted blocks, some of which must contain undiscovered segments of the same ore beds that have been partly developed to date. Possibly the terrain is a thrust sheet which rode over an uneven surface, thereby breaking into disorganized blocks.

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July 11, 1957

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A CONTRIBUTION ON THE HECTOR, CALIFORNIA BENTONITE DEPOSIT

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ABSTRACT

The unique Hector bentonite occurs along a northwest-trending fault zone for a distance of about five miles. Hot springs emanating along this fault during Pliocene (?) time deposited travertine in a then existing lake in which sand, marl and silicic pyroclastics also were being deposited. The tuff lying on the travertine benches was altered to saponite by solutions containing lithium and fluorine in the last stages of hot spring activity, with the magnesium being extracted from the lake water. Analcime, representing alteration of the tuff when the springs were inactive, is found below and above the bentonite bed. Clinoptilolite is present directly associated with the hot spring activity.

The amount of travertine decreases to the northwest as do the contents of lithium, fluorine, and magnesium in the clay, which approaches an aluminum montmorillonite in composition. In a restricted basin where magnesium is available, acid solutions from hot springs apparently produce a chemical system that forms a trioctahedral bentonite preferentially to a dioctahedral variety even though the parent material approximates the chemical composition of an aluminum montmorillonite.

Minor faulting and slumping have produced gouge zones and small downward displacements of the irregular bentonite lenses on the southwest side of the main fault. The deposit is located in a valley of low relief; the dominant structural feature is the high, developed by the deposition of sediments and pyroclastics on the travertine benches. River gravels and muds, and a basalt flow in places, unconformably overlie the series.

INTRODUCTION

A FIELD and laboratory investigation of the Hector bentonite deposits was begun in October, 1955 primarily to study the genesis of this unique clay mineral.

The Hector bentonite deposits are located in the Mojave Desert approximately 34 miles east of Barstow, California on U. S. Highway 66. There are two groups of claims in the Hector area: the South Group located three miles south of Hector Station on the Santa Fe Railroad, and the North Group, six miles northwest of the South Group (Fig. 1).

Production from the Hector bentonite deposits was initiated in 1931 and since then has been continuous. Old workings, including several shafts and open pits for 6,700 feet along a travertine ridge in the South Group, are reported to have yielded 25,000 tons of bentonite (18).

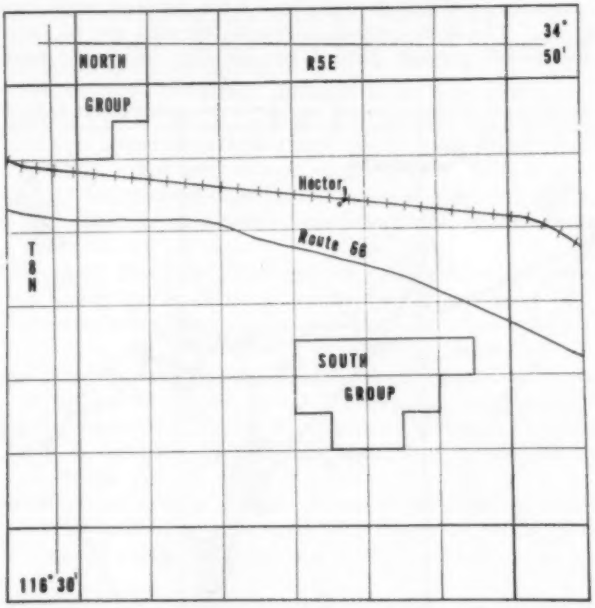

FIGURE 1. Index map of bentonite claims in the Hector area.

These old workings, now idle, in the South Group are represented by (1) the Old Lemon Mine, an inclined shaft that follows the travertine ridge down dip near the main pit to a depth of 300 feet, (2) the main pit, approximately 50 feet in depth and 150 feet in diameter, and (3) a smaller pit northwest of the main pit. The older workings in the North Group include several small mining prospect pits and shafts.

Present production is from the Inerto Mine of the Inerto Company and from the Schundler Mine on the Eyrite Claims leased by the Baroid Sales division of the National Lead Company, both in the South Group.

The Schundler Mine, located just southeast of the main pit, consists of a vertical shaft 107 feet deep with workings at the 40 and 70 foot levels. The

Schundler produced 10,000 tons of high-magnesian bentonite from 1947 to 1951 (19).

The Inerto Company Mine, adjoining the National Lead Company lease, has an inclined shaft that follows the bentonite with drifting and cross cutting to about 70 feet in depth. Production from the Inerto has averaged 250 to 300 tons a year since 1946 (19). Only high-grade magnesian bentonite is produced for specialized uses such as beverage clarification.

GEOLOGY

There are only a few surface exposures of the lithologic units in the Hector area (Fig. 2). The underground mines in the area are of little value in showing the overall geologic picture, because they follow the bentonite and

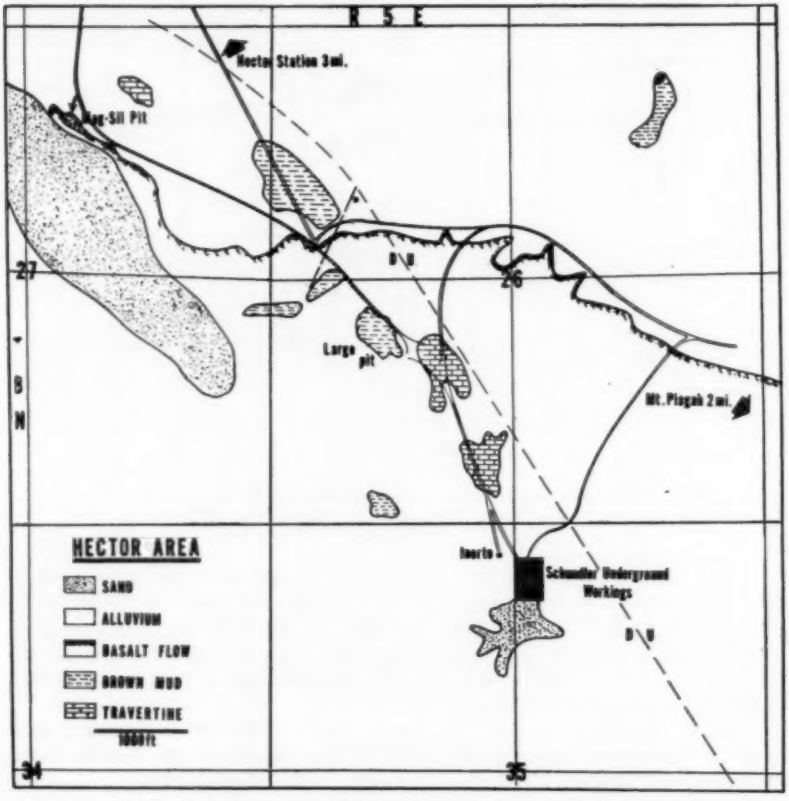

FIGURE 2. Map of geology and mine workings in the South Group. (Based on company maps of the Baroid Sales Division of the National Lead Company.)

travertine; hence, knowledge of the geology of the area around the bentonite deposits is based chiefly on exposures in the open pits.

The andesite flow upon which the travertine and bentonite rest is probably the Red Mountain andesitic series of Lower Pliocene (?) age. The bentonite itself and the altered tuff beds and brown mud are also of probably Lower Pliocene age and a part of the same Red Mountain series. A description of the Upper Red Mountain andesitic series in the Newberry Mountains about eight miles southwest of the South Group, given by D. L. Gardner (4), follows: "Interbedded with the lava flows are beds of yellow agglomerate and tuff. The agglomerates are composed of angular fragments of lava up to six inches in diameter embedded in a tuffaceous yellow matrix. The tuffs are white or yellow in color, fine-grained, and consist of fragmentary feldspar, biotite, hornblende, and altered glass."

Overlying the Red Mountain andesitic series are post-Red Mountain andesitic gravels 5 to 10 feet in thickness. Fragments of Mesozoic silicic intrusions make up a large part of these gravels with some Tertiary Red Mountain andesite. Bedding is not well defined in the gravels, with a size range of several inches to fine-grained material indicating a deposition as alluvial fans and cones. The gravels are overlain by a brown mud in the same series, up to 5 feet in thickness.

An olivine basalt flow from Mt. Pisgah caps the post-Red Mountain gravels in the South Group but is absent in the North Group. It is Pleistocene to Recent in age, and forms the youngest and least-altered rock in the bentonite area. Thickness in the South Group ranges from 5 to 50 feet. Aeolian sediments of variable grain size and thickness overlie the basalt in places.

There are three fault systems in the Hector area; north-south, east-west, and northwest-southeast. The latest and most pronounced system trends northwest. D. L. Gardner (4) states that the faulting is predominately of the normal Basin-Range type.

The bentonite claims lie in a major structure, the Barstow-Bristol trough. This trough extends from a point north of Barstow southeast to the Bristol Basin, a distance of about 110 miles, and at the bentonite claims is about 16 miles wide.

Numerous northwest-trending faults occur within the trough itself. The North and South bentonite claims lie along such a fault from which sand was seen to spurt during a recent earthquake. Otherwise the presence of the fault cannot be ascertained even on aerial photographs of the area.

PREVIOUS LABORATORY INVESTIGATIONS

The Hector bentonite is unique in that it has been reported by Foshag and Woodford (3) and Strese and Hofmann (17) to be essentially the magnesian end member of the montmorillonite group with nearly a total absence of aluminum. Lithium substitutes for magnesium in the octahedral position and there is partial substitution of fluorine for hydroxyl groups.

Strese and Hofmann (17) proposed the name "hectorite" for this mineral. Although Cox (2) first used the name hectorite for an alteration product of

pyroxene, the term was not accepted or used for more than 50 years, and the present usage of the name hectorite, therefore, does not conflict with Dana's rules of nomenclature.

A number of chemical analyses of hectorite have been reported (3, 9, 12, 17, 18). The structural formula for hectorite as given by Ross and Hendricks (12) is:

$$Na_{.39}(Mg_{2.67}Li_{.40}Al_{.01})Si_4O_{10}(F,OH)\ 2$$

and by Kerr (9):

$$Na_{.33}(Mg_{2.71}Li_{.34}Al_{.000})Si_4O_{10}(F,OH)$$

Kerr (12) mentions that, of all the clay samples spectrographically analyzed, the Hector samples were the highest in boron with an average value of 0.035 percent by weight. Extensive deposits of colemanite occur in the Calico Mountains about 15 miles northwest of the South Group in shaly lake beds of Miocene age, and it is not surprising that the ascending hot spring waters acquired a relatively high boron content and imparted some of this boron to the hectorite in the process of its formation.

Strese and Hofmann (17) first synthesized saponite from $MgCl_2$ and silica gels in the presence of various concentrations of NaOH and KOH. Higher concentrations of KOH resulted in the formation of micaceous minerals, while NaOH resulted in the formation of saponite over a wide concentration range.

Hauser and Reynolds (5) synthesized montmorillonites from glasses of a normal aluminum bentonitic composition and a natural obsidian from Yellowstone National Park. Results indicated that pH and compositional latitudes were much greater in the presence of $Mg(OH)_2$ than with alkalies and other alkaline earths.

Noll (11), like Hauser and Reynolds, in his synthesis of montmorillonite from $Al_2O_3:4SiO_2$ gels at 300° C concluded that the presence of magnesium is of greater importance in the formation of montmorillonite than the pH of the altering solutions. Roy and Roy (13) in their study of the stability of minerals in the system $MgO\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O$ found that the magnesium-aluminum montmorillonites containing no alkali in the exchange position were stable up to 480° C.

The cation exchange data for hectorite found in the literature seem to be in essential agreement. Kerr (9) lists the cation exchange capacity of hectorite dried to a constant weight at 105° C with estimated 1 percent impurity to be 117.5 milliequivalents NH_4+ per 100 grams, while Ross and Hendricks (12) found the cation exchange capacity of hectorite to be 84 milliequivalents Ba_2+ per 100 grams. The authors' determination on the purified hectorite was 115 milliequivalents Mn^2+ per 100 grams. Karsulin and Stubican (7) correlated cation exchange capacity with the magnesium to aluminum ratio in synthetic montmorillonites.

Hectorite was first studied optically by Foshag and Woodford (3), and later by Strese and Hofmann (17), Ross and Hendricks (12), and Kerr (9).

The X-ray diffraction data on hectorite have been reported by Kerr (9), Strese and Hofmann (17), and Nagelschmidt (20).

PREVIOUS THEORIES OF GENESIS

Several theories for the genesis of hectorite have been proposed. Foshag and Woodford (3) reported the hectorite in the South Group to occur in a small anticline in a Tertiary volcanic series and considered the origin of the hectorite to be similar to that of normal bentonite. Relict structures, such as shards, were noted that indicate a bentonite origin. Calcite, which they reported to be a major impurity in the hectorite, was believed to be a recrystallization product of overlying limestone.

Ross and Hendricks (12) attributed the formation of hectorite to the action of highly magnesian solutions on an overlying brown tuff into which the hectorite grades. Thin-section examinations also indicated a bentonitic origin for the hectorite.

Kerr (9) thought the hectorite was derived by the hydrothermal alteration, at medium temperature, of a basic volcanic ash, or possibly a flow. Intense shearing and folding were considered to have produced a commercially valuable deposit from an otherwise thin hectorite layer. In the volcanic series, bentonite occurs in layers that alternate with less-altered ash, silty clay and limestone beds. Impurities in the hectorite were found to be chiefly calcite with less than 1 percent sodic plagioclase.

METHODS OF INVESTIGATION

Field relationships of the various lithologic units in the North and South Groups were studied in November 1955 and May 1956, and samples were procured during that time. Thirty-three samples were taken in the Schundler underground workings wherever a lithologic change was encountered (Fig. 3). The samples were waxy clay, mixed clay and travertine, travertine, and chalcedony and calcite nodules. Other sampling included 20 samples of travertine from outcrops in the area, a series of 8 samples in the large pit from the gravel underlying the lava to the hectorite bed, 14 samples from the Inerto Company Mine in the South Group, a vertical series of 4 samples in the Mag-Silica pit in the South Group from the hectorite to the brown mud, 8 samples of a section exposed in a 20 foot shaft in the North Group, and 3 samples from the Lotion pit in the North Group of bentonite, travertine, and overlying conglomerate.

All the above samples except the travertine outcrop samples were ground to -200 mesh, and vapor solvated with ethylene glycol to characterize any montmorillonite group minerals present at 17.0Å basal spacing. The samples were then run on a Norelco X-ray diffractometer unit.

Thirteen thin-sections were made of the various lithologic units encountered in the study including the brown mud, travertine, travertine and bentonite admixtures, waxy bentonite, and a chalcedony nodule. Where zeolites were identified from the X-ray data, grain mounts were examined. Chemical anal-

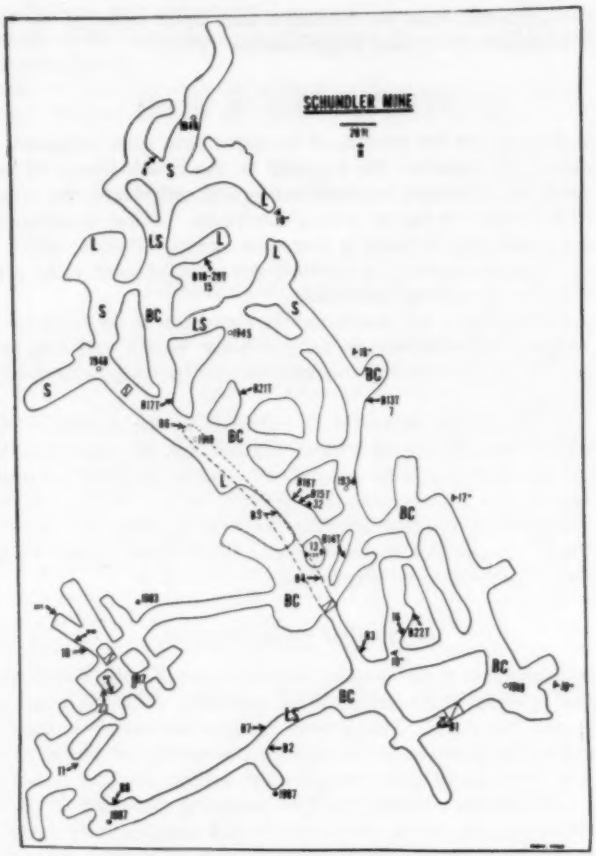

FIG. 3. Map of underground workings and sample locations, Schundler Mine, South Group. (From National Lead Company base map.) L=lava capping, S=soil capping, LS=limestone capping, BC=brown clay capping. ○ Elevations in workings. ● Surface elevations.

yses were made of the purified commercial white bentonite from the Schundler Mine in the South Group, bentonite from a twenty-foot shaft in the North Group, of the acid residue from travertine at the bottom of the main shaft of the Schundler Mine in the South Group, and of the clinoptilolite from the − 200 mesh size fraction of the North Group aluminum bentonite.

Selected samples of bentonite from the North and South Groups were dissolved in HF-H_2SO_4 and analyzed for lithium on a Beckman DK-11 flame photometer.

RESULTS

Though the major northwest-trending fault system was not observed in the field, the travertine ridge formed by the hot springs emanating along this fault system is easily discernible. There are no mine workings or clay outcrops between the North and South Groups; structural and lithologic relations are, of necessity, inferred. A series of holes was drilled by the National Lead Company on their lease in and around the South Group, but the drill hole data were not available at the time of this study. Also observed was a series of northeast-trending minor faults cutting the travertine and bentonite in the South Group. Slumped bentonite beds lie on the travertine benches (Fig. 4). This probably occurred as the tuff, from which the bentonite originated, piled up on the steep sides of the ridge. The bentonite is interbedded with the travertine as the hot springs activity was contemporaneous with tuff deposition during Pliocene (?) time. Tuff and ash beds, deposited

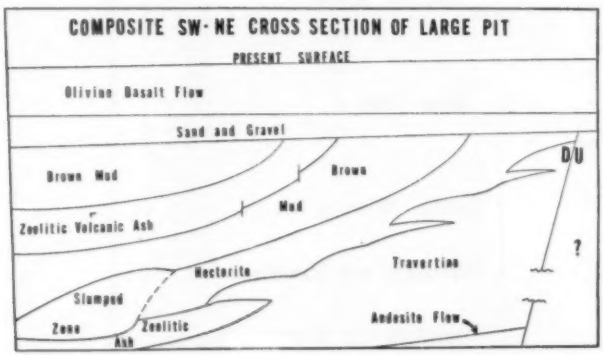

FIGURE 4. Generalized northeast-southwest cross-section of the geology of the Main Pit, South Group.

subsequent to hot spring activity, lap up onto the travertine ridge, which had been reported as an anticline. These tuff and ash beds are overlain unconformably by a brown mud and gravel. The youngest lithologic unit, olivine basalt from Mt. Pisgah, overlies the gravel in the South Group but is absent in the North Group (Fig. 5).

A mineralogical examination of the various rock units by X-ray diffraction showed that the hectorite of the South Group contains much admixed calcite and some sodic feldspar as impurities. The travertine also contains glass, sodic feldspar, and quartz. The total of these impurities averages 1 to 3 percent, but in places the ash and tuff content is high. The travertine at the bottom of the main shaft of the Schundler Mine contains 40 percent of pyroclastic material. An analysis of the HCl residue from travertine sample is given in Table 1. It is dacitic in composition as postulated by Foshag and Woodford (3) and represents a portion of the original tuff, the source rock

for the bentonite, which was preserved from alteration by the contemporaneous deposition of travertine.

Table 1 also gives an analysis of a sample of North Group bentonite which contains a small amount of zeolite; it is essentially a normal aluminum bentonite as Tucker and Sampson (18) first reported. The structural formula of this aluminum bentonite corrected for zeolite, gypsum, calcite and soluble chlorine content, and calculated by the method of Ross and Hendricks (12), is:

$$Na_{.75}K_{.06}$$
$$(Li_{.07}Mg_{.50}Al_{1.62})Si_4O_{10}(OH)_{1.84}F_{.16}$$

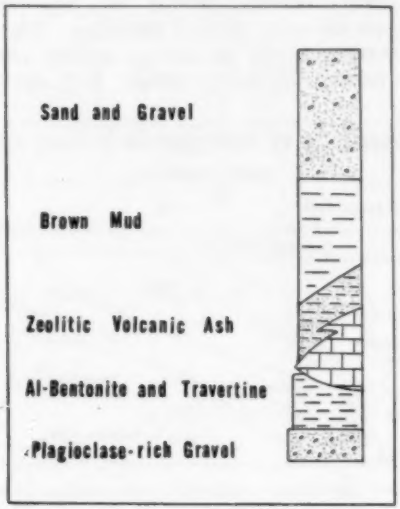

FIGURE 5. Generalized section of the strata of the North Group.

The structural formula of hectorite corrected for gypsum, calcite and soluble chlorine content, and calculated from the analysis in Table 1, is:

$$Na_{.28}K_{.01}\frac{Ca}{2}{}_{.02}$$
$$(Li_{.33}Mg_{2.65}Al_{.02})Si_4O_{10}(OH)_{1.35}F_{.65}$$

About 1 percent of zeolite occurs in this North Group aluminum bentonite as an impurity. This zeolite was not found in the hectorite of the South Group, although analcime is found there just below the hectorite and travertine, probably marking the beginning of hot spring activity. The zeolite in the North Group also is interbedded with the uppermost travertine and probably is correlative with the last stages of Pliocene (?) hot spring activity. Nowhere is this zeolite found not associated with the travertine. The chemical

analysis (Table 1) and the X-ray diffraction data (Table 2) are presented for this zeolite found in the above locations.

The data indicate that this zeolite is very similar to the clinoptilolite of Schaller (15), a member of the mordenite-ptilolite group, to which he assigned the formula $10SiO_2 \cdot Al_2O_3 \cdot (Ca, Na_2, K_2)O \cdot 7H_2O$. The formula calculated from the chemical analysis of the zeolite from Hector is $10SiO_2 \cdot Al_2O_3 \cdot (Ca, Na_2, K_2)O \cdot 6H_2O$. Ptilolite and clinoptilolite have the same chemical composition but can be distinguished optically (1, 15). The zeolite of this study

TABLE 1

CHEMICAL ANALYSES
(S. S. Goldich, Analyst)

	1	2	3	4
SiO_2	64.85	58.99	55.17	66.21
Al_2O_3	14.32	16.62	.33	11.02
TiO_2	.83	.17	.01	.10
Fe_2O_3	2.39	1.82	.12	.84*
FeO	.73	tr.	tr.	n.d.
MnO	.04	.01	tr.	.01
MgO	1.61	4.37	24.51	.39
Li_2O	.04	.24	1.14	tr. (.01)
CaO	3.73	.40	.90	1.33
Na_2O	3.26	5.13	2.20	5.82
BaO	.07	.02	.00	n.d.
K_2O	2.38	.54	.08	1.04
Rb_2O	.02	.00	.00	n.d.
H_2O^+	2.31	4.67	2.84	7.12
H_2O^-	2.94	4.83	8.93	4.66
CO_2	.00	.06	.63	.60
F	.18	1.14	4.75	.03
Cl	.08	.67	.21	.28
SO_3	.03	.58	.00	.05
P_2O_5	.05	.03	.05	n.d.
	99.86	100.29	101.87	99.50
Less O = F & Cl	.09	.63	2.04	.07
	99.74	99.66	99.83	99.43

* Total Fe and Fe_2O_3

1. Acid residue of travertine from base of main shaft of Schundler Mine.
2. Aluminum bentonite from the North Group.
3. Hectorite from the South Group.
4. Clinoptilolite from the North Group bentonite.

is monoclinic, tabular and not fibrous, with undulatory extinction and a mean index close to 1.480.

Although clinoptilolite and heulandite have practically identical X-ray diffraction patterns, as reported by Bramlette and Posnjak (1), the optical and chemical data show the zeolite encountered in this study to be clinoptilolite.

Irregularly-shaped calcite and chalcedony nodules are common in the bentonite of the South Group, often with manganese oxide centers. These nodules range in size from less than an inch to two feet across. The spherical

nodules in the North Group are calcite only and are less than four inches in diameter.

Dolomite, magnesite, and fluorite were sought in all travertine and travertine-bentonite samples, but no trace of fluorite or magnesite was found either in thin sections or X-ray diffraction patterns of these samples. Dolomite was found associated with limonite and hectorite on a minor fault plane in the Inerto Mine, probably of secondary origin, but the travertine was otherwise dolomite-free. The magnesium evidently was extracted from the circulating lake waters.

TABLE 2

XRD DATA

1		2		3	
dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1
13.4	10	8.93	100	8.93	100
8.93	100	7.92	23	7.90	5
6.30	15	6.76	13	6.71	3
5.73	15	5.97	11	5.22	2
4.48	20	5.13	18	5.07	5
3.98	35	4.66	21	4.61	7
3.46	15	4.47	12	4.44	4
3.38	25	4.10	10	4.15	2
3.18	35	3.98	72	3.95	15
3.02	15	3.91	14	3.87	6
2.88	10	3.72	10	3.71	4
2.81	10	3.56	10	3.56	2
2.56	5	3.43	22	3.45	2
2.51	5	3.40	5	3.41	5
		3.18	22	3.18	4
		3.13	20	3.11	5
		3.08	7	2.96	32
		2.97	47	2.80	10
		2.81	25	2.70	7
		2.74	18	2.50	4
		2.68	5	2.23	7

1. Mordenite from Nova Scotia.
2. The zeolite of this study from the North Group bentonite.
3. Heulandite from West Paterson, New Jersey.

Strese and Hofmann (17) reported that minute gypsum crystals were hand-separated from their samples of hectorite from somewhere in the South Group, but none was identified in the course of this study.

Above the hectorite-bentonite lie alternating beds of brown tuff and volcanic ash that lap up onto the travertine mounds and benches. The brown tuffs are only partly altered to analcime with feldspar and analcime content about equal. They also contain quartz and some secondary calcite. These volcanic ash beds are nearly completely altered to analcime. On the northwest face of the main pit and in the Schundler Mine, a brown lake mud directly overlies the hectorite and represents the incompletely altered tuffaceous material from which the hectorite was derived, as Foshag and Woodford (3) reported. The mud ranges up to 10 feet in thickness. It is partially altered to hectorite

at its base, yielding a brown waxy hectorite of a high iron content containing numerous calcite nodules that average about an inch in diameter. The middle of this mud unit contains hectorite in the form of small stringers and grades into an analcime tuff very similar to the brown tuffs which overlie it. In places in the Schundler Mine, the brown mud is interfingered with the hectorite.

An optical examination of the brown mud shows the following minerals, listed in the order of abundance: quartz, calcite, andesine, analcime, biotite, a

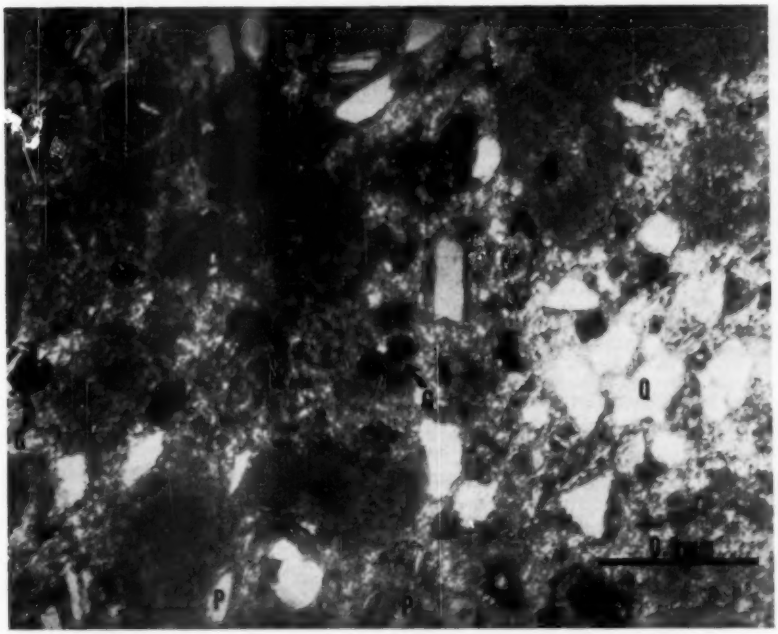

FIG. 6. Thin-section of travertine, hectorite, and tuff from the Mag-Silica pit, South Group. Crossed—nicols. P—plagioclase, Q—quartz, G—glass.

pyroxene, some magnetite and an occasional tiny zircon crystal. This is essentially the list given by Foshag and Woodford (3).

Figure 6 is thin-section of travertine and bentonite from a slump zone in the Mag-Silica pit of the South Group. Note the large amount (15%) of plagioclase (mostly andesine). The plagioclase phenocrysts vary in size from 0.1 to 0.5 mm and are partly replaced by bentonite and calcite. Considerable glass is also present (up to 10%) in a groundmass of calcite and bentonite. A few biotite, pyroxene, and magnetite crystals were also noted. An analysis of this tuff from which the bentonite was derived is presented in Table 1.

Seventeen samples from the North and South Groups were analyzed for their lithia content to determine whether there are systematic variations in the lithia content of the bentonite (Table 3). The lithia content was then compared with the X-ray diffraction data to ascertain the amount of impurities (calcite and feldspar) in each sample to arrive at a corrected figure for the bentonite lithia content.

The results showed that there is practically no variation in the lithia content of the bentonite in the Schundler Mine, Inerto Mine, and Main Pit in

TABLE 3

RESULTS OF LITHIUM ANALYSES

Sample Description	% Li_2O
Inerto Mine, South Group	
Travertine and hectorite	0.52
Hectorite	1.06
Schundler Mine, South Group	
No. 16 Hectorite, some calcite	1.01
No. 15 Hectorite and calcite	.54
No. 11 Hectorie and calcite	.54
No. 7 Hectorite, some calcite	.99
No. 10 Hectorite	1.08
No. 32 Hectorite	1.08
No. 3 Hectorite	1.08
No. 13 Brown, Fe-stained hectorite	.67
No. B-10 Hectorite and calcite, some feldspar	.58
No. B-19 Fe-stained hectorite at base of brown mud	.54
Main Pit, South Group	
Hectorite and calcite	.62
Brown mud, analcime-rich, northeast face	.22
Mag-Silica Pit, South Group	
Hectorite and calcite	.37
North Group	
Lotion Pit, aluminum bentonite	.15
Prospect Shaft, aluminum bentonite (See Table 1 for chemical analysis)	.24
Clinoptilolite and analcime rich volcanic ash interbedded with travertine	0.0

the South Group, but that the lithia content falls off from 0.2 to 0.4 percent between the above locations and the Mag-Silica Pit. There is an even greater drop in percent of lithia (0.4 to 0.6 percent) between the Mag-Silica Pit and the North Group. This drop in lithia content coincides with a drop in the intensity of alteration of the tuff to bentonite and a falling off from the South to North Group of the amount of travertine associated with the bentonite. It is evident that hot spring activity decreased from the South Group to the North Group.

Electron micrographs were taken of the North Group aluminum bentonite

and the South Group hectorite. The hectorite exhibits a lath-like habit of crystal development, as first reported by Humbert and Shaw (6), while the aluminum bentonite from the North Group shows the poor crystal habit of normal bentonites.

DISCUSSION

From the field and laboratory data presented, it is seen that the formation of bentonite is related to former hot spring activity in a restricted lake environment. Such an origin is by no means unique, although the high content of lithium and fluorine is the unusual characteristic of hectorite.

Schroter and Campbell (16) give analyses of saponitic clays from two Nevada locations. The Clay City deposits are described as having been derived from clastic sediments accumulated in ancient alkaline lake basins. Domes and hummocks of calcium carbonate point to the formation of calcareous tufa domes in the ancient lake basins. These tufa domes are left behind in the course of mining the saponitic clay. Schroter and Campbell conclude that there is no evidence that saponite replacements of the clastic sediments were formed through agencies other than those of circulating alkaline waters. Similarly, there is no evidence (no dolomite or magnesite in the travertine) to indicate that the magnesium came from the hot springs associated with the Hector bentonite.

The saponitic clay from Pioche, Nevada is of similar origin, being an alteration, or replacement of pyroclastics near hot springs in a restricted lake environment (16).

The alteration of an intermediate zeolite to a montmorillonite is not unique. Bramlette and Posnjak (1) found that pyroclastic material commonly alters to an intermediate zeolite, which they identified as clinoptilolite, in bentonite deposits from the Miocene of California, Dome, Arizona, and Pedro, Wyoming. Kerr (8) reported that a Miocene bentonite from the Rincon formation near Ventura, California contained a zeolite with indices of refraction closely corresponding to heulandite. Kerr and Cameron (10) also reported the same heulandite-like zeolite in a bentonite near Tehachapi, California.

Clinoptilolite, then, is quite widely associated with bentonite. An optical examination of the -200 mesh size fraction from the North Group bentonite prospect shaft shows the glass to be altered to clinoptilolite which in turn is altered to a normal aluminum bentonite. The magnesium bentonite of the South Group contains no clinoptilolite.

Roy and Sand (14) reported that montmorillonite synthesized at higher temperatures and containing maximum silica yielded uniform, lath-like montmorillonite crystals. This morphology is exhibited by hectorite. The alteration of pyroclastics to magnesium bentonite in the South Group, having been altered to a greater degree and in well-developed crystals, took place at somewhat higher temperatures. The many large chalcedony nodules in the South Group are concentrated where the magnesium bentonite is most pure (areas of greatest alteration) indicating that the alteration progressed in a silica-rich environment.

SUMMARY

In the Hector area, tuff and volcanic ash of high glass content were deposited in a restricted alkaline lake environment near or upon travertine mounds or terraces that were being formed as a result of hot spring activity in the lake. Alteration of the tuff to clinoptilolite took place initially under the influence of hot spring activity. In all ashes and tuffs deposited prior to, or antedating, hot spring activity, the zeolite analcime was formed in the same restricted alkaline lake environment, and bentonites did not develop from further alteration of the analcime. In some areas, the initial tuff was quickly covered by travertine which protected it from further alteration by hot spring waters. Slumping of the partially altered tuff occurred on the sides of the travertine mounds, giving the bentonite its pocket-like development as an ore.

During the alteration of the clinoptilolite to hectorite, lithium and fluorine were supplied, for the most part, by the hot spring waters, while the magnesium already present in the lake waters replaced the aluminum of a normal aluminum bentonite in proportion to the proximity of the altering material to the center of hot spring activity. The magnesium bentonite in the South Group, because it developed in the presence of excess silica and nearer the centers of hot spring activity, exhibits a well-developed, lath-like crystal habit.

Much geological work remains to be done in the Hector area. Drill hole data would be of much value, especially in the area between the North and South Groups and on the northeast side of the northwest trending fault line that transverses the North and South Groups. The area southeast of the Schundler Mine also remains largely unexplored.

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SCHEELITE IN FELDSPATHIZED GRANODIORITE AT THE VICTORY MINE, GABBS, NEVADA

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ABSTRACT

Economic quantities of scheelite occur in a sheared and feldspathized portion of the Illinois granodiorite stock, near Gabbs, Nevada. The granodiorite intrudes dolomite and shale of probable Late Triassic age.

A westward projection of the stock, and adjacent sedimentary rocks, were subjected to strong compressive forces during or shortly after the em-

[1] Mr. Wyatt died in September, 1956.

placement of the granodiorite. The dolomite is thrust over the granodiorite, and the latter is intensely sheared for several hundred feet from the contact. The scheelite mineralization is one stage of a metasomatic replacement process; the metasomatizing solutions were guided by the shear and fracture zones. The mineralogical changes effected are concentrated where crushing and fracturing were most intense, and particularly where there was recurrent crushing. Four successive stages of metasomatic alteration can be recognized.

(1) Feldspathization; the dominant process is replacement of quartz by orthoclase and oligoclase.

(2) Ore-type metasomatism; replacement of quartz and orthoclase by plagioclase, accompanied by minerals such as garnet, diopside and hastingsitic amphibole.

(3) Scheelite mineralization; essentially confined to the ore-type rocks where they were subjected to crushing.

(4) Quartz veining.

In spite of the intense crushing no mylonitic rocks were observed, the feldspathized rocks are commonly coarse-grained, and low-temperature minerals such as clay minerals and chlorite are generally absent. These features indicate a high temperature for the mineralization, which probably took place while the intrusion was still hot.

INTRODUCTION

The Victory Mine (Fig. 1) is about eight miles north of Gabbs, Nye County, Nevada, approximately 65 miles southeast of Fallon.

FIG. 1. The Victory Mine area looking N 25° W. The mine glory hole is near left center. Victory Ridge is at right and a few of the larger quartz veins are visible on the slope. The dark band at the extreme right is the andesite dike. The ridge at the left is metamorphosed shale with dolomite eastward to the Dougan thrust.

Scheelite mineralization was discovered on the Victory claims in 1944 and in 1949 Mr. Lee Dougan bought the property. He discovered a large body of ore, which is at the site of the Victory Mine shown on the geologic map, Figure 2, and production started in 1951.

No water was available near the mine for milling purposes so a mill was built near the town of Gass, and the ore is trucked to it.

It is a pleasure to acknowledge the financial support of this project by Mr. Lee Dougan and his permission to publish this report. Thanks are due to the Shell Foundation for Fundamental Research in Geology at Stanford University for the chemical analyses.

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GEOLOGICAL SETTING

The Victory Mine is in the southwest part of the Illinois granodiorite stock. The intrusion, about five miles long in a north-south direction and approximately three miles wide, cuts dolomites and shales that are considered by Muller and Ferguson (1) to be members of the Luning formation of Upper Triassic age. They consider the intrusion to be of Jurassic age.

On the southwest side of the Illinois stock there is an apophysis of granodiorite forming a separate ridge, known as the Victory Ridge. It is about one mile long and from 800 to 1500 feet wide. In this area scheelite mineralization is found in sheared and feldspathized granodiorite.

STRUCTURAL GEOLOGY

The major structural features in the rocks of Victory Ridge are related to strong compressive forces that were active soon after emplacement of the granodiorite. Features giving evidence for the compression are: (1) the Dougan thrust around the west, north, and northeast sides of the Victory Ridge granodiorite, (2) the intense west-dipping shearing of the granodiorite along the west side of the granodiorite with striations parallel to the dip, and (3) the strong north-south, west-dipping fracturing in the granodiorite.

Thrust Faults.—The Dougan thrust fault forms the contact between the granodiorite and the dolomite, and at this contact the dolomite has generally been sheared and pulverized (Fig. 3). The granodiorite is crossed by shear zones, fractures, and innumerable quartz veins, but except in two or three instances all of these features are terminated at the Dougan thrust and do not cross into the dolomite. The granodiorite also contains an andesite dike that does not penetrate the dolomite, but the younger lamprophyre dikes cross freely into the dolomite. The thrusting has removed most of the original contact rocks except in a few places where thin bands of tactite are preserved against the granodiorite below the thrust surface.

Along the west side of Victory Ridge the thrust dip averages about 45° west. At the north end of the ridge the dolomite overlaps the granodiorite and probably once covered it to the south. East of the crest of the ridge the thrust dips to the northeast.

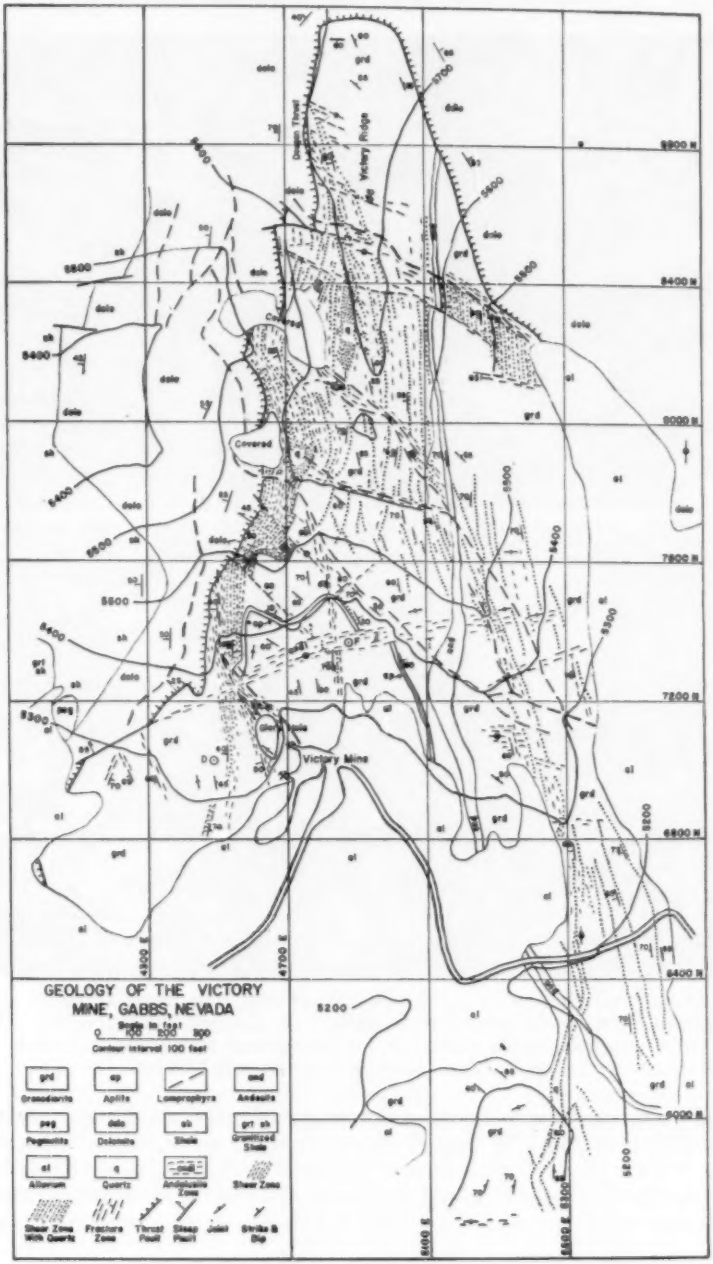
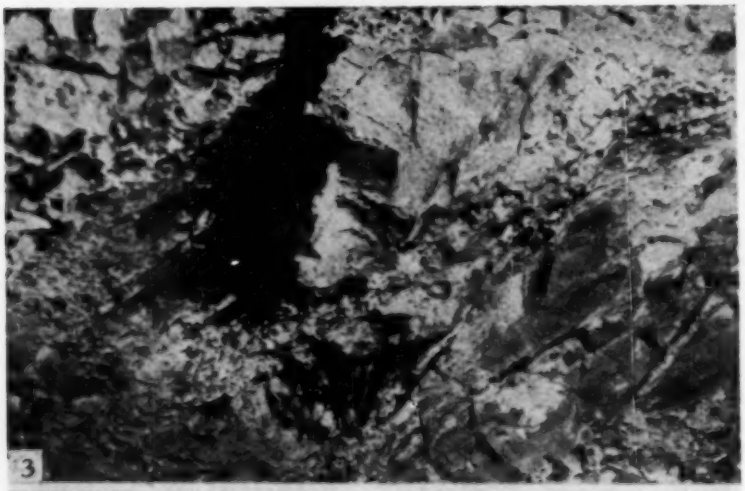


FIG. 2. Geologic map of the Victory Mine area.



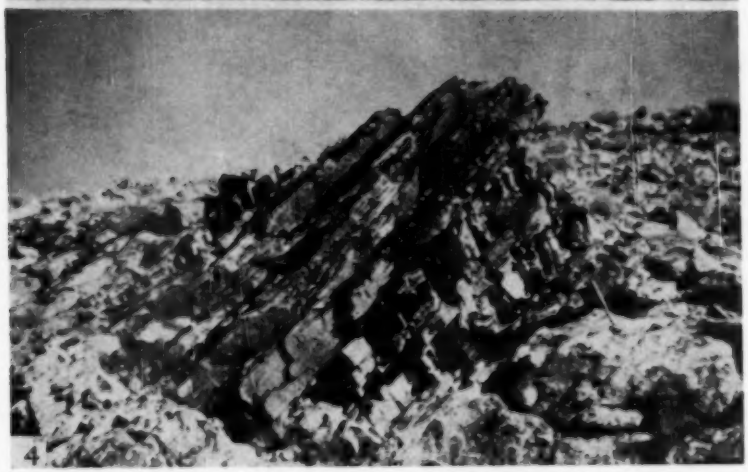


FIG. 3. The Dougan thrust surface, behind pick, with dolomite thrust over granodiorite. About 18 inches of pulverized rock separates the two walls.

FIG. 4. Shearing in the granodiorite in the footwall of the Dougan thrust. A small thrust cuts across the shear planes behind the pick handle.

The amount of displacement on the Dougan thrust is not known. About one-half mile north of the mapped area there is an undulating fault, dipping flatly to the south, with a displacement of about 1600 feet; the south side has moved relatively east. This fault may be the extension of the arcuate Dougan thrust.

Culmination of the thrusting followed the shearing and the quartz veining in the granodiorite.

Shearing.—Correlative to the thrusting, but mostly older, are several zones of intense shearing in the granodiorite (Fig. 4). The shearing is not all of the same age and probably took place recurrently throughout the period of compression.

The oldest shear zone strikes N 10° W along the west edge of the glory hole (Fig. 2). This zone dips to the west and forms the hanging wall of the ore in the Victory Mine. Merging with this shear zone is the contemporaneous west-dipping, N 40° W shear zone at the north end of the glory hole. The zone extends north to about the 7600 N. coordinate where the Dougan thrust over-rides it.

The N 10° W shear zone apparently splits at the junction with the N 40° W shearing, with the easterly portion forming the arcuate aplite shear zone. Small outcrops of aplite occur within the area of intersection of the two shear zones and aplite is also exposed in the hanging wall of the mine workings. The aplite zone flattens toward the north and makes a sharp bend to the east where its continuation forms a broad arc with a dip of 10° to 20° N, gradually changing strike to the southeast with an easterly dip. The aplite in the shear zone to the north of the glory hole and the aplite in the hanging wall of the mine ore both show fine banding of the hanging wall rock and the contiguous portion of the aplite.

Cutting through this older shearing is a younger shear zone with a general north-south trend. Starting west of the glory hole, with a strike of about N 5° W, this zone follows a northerly course and gradually changes strike to approximately N 10° E. The dip flattens toward the north from 50° to 60° W to an average of about 25° W near the 7600 N. coordinate. In this latter area a few of the shear surfaces have accommodated greater displacement, turning into small thrusts that become flatter and cut across the other shears (Fig. 4).

A characteristic of this younger zone is the maze of quartz veinlets that follow the shear planes. The quartz almost always shows striations parallel to the dip and the ever present tourmaline crystals are elongated in the same direction. In contrast, there are practically no quartz veinlets in the older shear zone although the rocks there are much more feldspathized.

Still another shear zone occurs in the granodiorite in the northeastern part of the area. The shear planes strike about north-south and dip about 60° west. Quartz veinlets also characterize this zone. The width of this zone is greater than its length, there being no indication that it extends longitudinally beyond the fracture zones that bound it. Probably the ruptures are due to deformation by a couple between the boundary fracture zones.

Fractures.—The granodiorite of Victory Ridge is cut by innumerable fractures, many of which are filled by quartz veins similar to those of the younger shear zones. Some of the larger veins may be seen in Figure 1 toward the top of Victory Ridge.

The most consistent fracture pattern strikes about N 10° W but this trend varies locally between N 30° W and N 10° E. The average dip is approxi-

mately 65° W except along the east side of the area where it varies between 30° W and vertical. Many of the quartz veins show striations parallel to the dip and thus the fractures are small faults, but are here differentiated from the shear zones by the much greater intensity of shearing in the latter.

In addition to the N 10° W fracture pattern there are a number of narrow fracture zones striking between N 30° W and N 80° W. They mostly dip steeply to the southwest but a few dip northeast. Some of these zones have accommodated a small amount of displacement. The southwest-dipping fracture zone about 100 feet northeast of survey station F, which a lamprophyre dike follows, was found by diamond drilling to cut the northeast-dipping aplite dike with a reverse displacement of about 30 feet. The fracture zones generally show evidence of recurrent movement having been active both before and after the N 10° W fractures were formed, and a few offset the Dougan thrust. The lamprophyre dikes commonly follow this fracture pattern although the older andesite dike follows the N 10° W pattern north of the 6800 N. coordinate.

Generally the northwest fracture zones vary in width from 2 to 15 feet in contrast to the N 10° W fractures which, on the whole, are single fractures. The N 10° W fractures generally contain quartz veins with a few narrow bands of feldspathized rock along the walls, whereas the rocks within the northwest fracture zones, south of the 7800 N. coordinate, are commonly extensively feldspathized but contain very little quartz.

In the northern part of the area a series of northwest fractures progressively cuts off the N 10° W fractures. They were initiated before the N 10° W fractures, but were subject to renewed movement. Commonly the N 10° W veins pass through the cross fractures but with a pronounced thinning, and quartz veinlets follow the cross fractures for a few feet. In other cases the quartz veins are offset a few feet, indicating renewed movement after the period of quartz veining.

Steep Faults.—Although many of the fractures and especially the fracture zones are small faults, there is one zone in the granodiorite with greater measurable displacement that does not coincide with any of the other structural patterns. This is the andalusite zone near the 7400 N. coordinate.

The andalusite zone strikes about N 75° E and is generally vertical or dipping about 85° N. From the eastern edge of the granodiorite west to the andesite dike it is a zone of closely spaced joints with no discernible displacement. In the central part, however, north of the Victory Mine, this zone has offset a quartz vein and the aplite dike about 80 feet horizontally, the relative displacement being eastward on the south side. Since the offset vein dips west and the aplite dike dips east, the actual displacement must have been dominantly horizontal. The quartz vein is offset in a series of steps, and narrow stringers of quartz in places follow the cross fractures for a short distance.

At the west end of the andalusite zone there is a steep, north-dipping fault that offsets the Dougan thrust about 200 feet, with the north side moved east. In addition, the quartz-bearing shear zone and aplite dike north of the glory hole are offset a short distance along this zone in the same direction. This apparent displacement is opposed to the previousiy described direction of dis-

placement. The earlier displacement apparently took place while the quartz vein was forming because quartz stringers follow the cross fractures, and the later displacement is younger than the thrusting.

In a drift following the thrust a short distance north of the steep fault there are horizontal striations in "leathery" gouge formed along the thrust surface. These are possibly related to movement induced by horizontal displacement on the steep fault.

Joints.—Prior to the rupturing of the granodiorite, two sets of joints had apparently developed in it. These formed a conjugate joint system striking about N 50° W, with one set dipping about 60° to 80° SW and the other 50° to 70° NE. This joint system was subordinated by a later conjugate system complementary to the compressive stresses. It strikes about N 10° W with one set dipping approximately 50° to 80° W and the other 50° to 70° E. In addition, there are many localized, erratic joint sets that were probably caused by variable stresses set up in small blocks of rock that are enclosed by fracture or shear zones.

Another type of localized jointing occurs in areas of strong feldspathization. The jointing in the Victory Mine is a good example of this. Within the area of feldspathization it is very intense but does not continue in the surrounding rocks. The closely spaced joints strike about north 50° W and are vertical. The feldspathized rock was somewhat crushed and many microscopic fractures developed.

IGNEOUS ROCKS

Granodiorite.—The granodiorite is a medium-grained, equigranular or seriate rock with a granitic texture. Much of the material from Victory Ridge is rather crushed and sometimes feldspathized, but there are areas of fresh material, particularly in the north. Mineralogically the fresh material is a quartz-rich, leucocratic, biotite granodiorite. The minerals present are as follows:

Quartz, forming 30–35 percent of the rock, is typical granitic quartz.

Orthoclase is subordinate to plagioclase, forming 18–22 percent of the rock. The orthoclase is always perthitic, and has $(-)2V = 61 \pm 3°$.

Plagioclase forms 40–45 percent of the rock. The plagioclase is near An_{25}, slightly zoned, and commonly shows one or two slight reversals of zoning. Commonly there is a thin outer zone that is much more sodic and locally, where adjacent to orthoclase, this outer zone passes into myrmekite.

Biotite generally forms less than five percent of the rock, and with it are associated small amounts of allanite, apatite, zircon, magnetite and rarely, sphene.

A few samples collected from the main body of the Illinois stock are all biotite granodiorite similar to the material from Victory Ridge.

Inclusions in Granodiorite.—Small xenoliths of more mafic material are rather common in the granodiorite, especially on the west side of Victory Ridge. These xenoliths are dominantly plagioclase and biotite, with lesser amounts of hornblende, quartz, and a little orthoclase. They resemble some of the granitized shale found adjacent to the intrusion (see below). When

involved in shear zones, these xenoliths are feldspathized in a manner similar to the granodiorite.

Aplite.—True aplite was not found in the granodiorite of Victory Ridge, although several aplite dikes were seen in the main body of the intrusion. However, in the Victory Ridge mass there are some dikes of leucocratic fine-grained granite referred to here as aplite. These are notably a flat-lying, semi-circular dike exposed just north of the Victory Mine, and the dikes that cap the ore in many parts of the mine. Zones of intense shearing parallel the margins of these dikes, the minerals being very fine-grained and streaked out, but there is little or no alteration of the feldspar. Locally, however, crushed zones of these dikes show metasomatic changes similar to those found where the ore occurs.

Pegmatite.—West of the Victory Mine, approximately at the dolomite-shale contact, is an irregular mass of pegmatite (Fig. 2). It is dominantly a coarse muscovite-orthoclase-albite-quartz pegmatite. Locally large crystals of garnet, tourmaline and andalusite are found. There are also some patches of medium- and coarse-grained graphic granite.

The pegmatitic material must have been mobile since inclusions of altered shale in the pegmatite are generally discordant to the bedding in the adjacent shale.

Andesite.—The andesite is porphyritic with abundant euhedral phenocrysts of green hornblende and plagioclase. The plagioclase is zoned from An 20 to An 37. The phenocrysts, which average about 60 percent of the rock, are set in a fine-grained groundmass of hornblende, plagioclase, chlorite, and a micropegmatitic intergrowth of quartz and orthoclase. The quartz constitutes about 5 percent of the total volume. Accessories are sphene, apatite and magnetite.

Lamprophyre.—The lamprophyre is spessartite, being composed dominantly of hornblende and plagioclase. The hornblende forms long idiomorphic crystals set in a mass of lath-shaped altered plagioclase. There are scattered small patches composed of calcite and chlorite, the shape of some suggesting pseudomorphs after pyroxene.

SEDIMENTARY ROCKS

Dolomite.—Dolomite forms the upper plate of the Dougan thrust and is in thrust contact with the granodiorite. It is dominantly a thin-bedded, recrystallized white to dark gray or bluish dolomite or dolomitic limestone. The top 50 feet of the formation becomes progressively more argillaceous as it approaches the shale contact. This upper, more impure, portion of the formation contains lenses of calc-silicate hornfels formed by thermal metamorphism.

Shale.—A quartz-rich andalusite hornfels overlies the dolomite. This hornfels was probably derived from an arenaceous shale by thermal metamorphism.

GRANITIZATION

Granitized Shale.—A portion of the shale west of the mine, contiguous with the pegmatite, shows features commonly described as granitization. These

granitized shales form an irregular east-west belt extending some 300 feet to the west of the mapped outcrop, where they disappear under talus and alluvium, so their extent is unknown.

Commonly the shale is changed to a coarsely gneissose rock, showing granitic layers alternating with darker bands relatively rich in mica and andalusite. The final product of granitization is a rather coarse-grained, leucocratic "granodiorite," which appears igneous in hand specimens but has an extremely irregular texture quite unlike the usual granodiorite. This type is composed dominantly of quartz, orthoclase, and sodic plagioclase, with minor muscovite, biotite and andalusite. Myrmekite is characteristic in these rocks.

CONTACT METAMORPHISM

Pneumatolitic Metamorphism.—The thrusting, which followed consolidation of the granodiorite, has removed most of the original contact rocks, but locally thin zones of tactite are preserved against the granodiorite. Probably the tactites were sufficiently competent to act, at least locally, as part of the rigid igneous body over which the dolomite was thrust.

The tactites are variable mineralogically, and are greatly complicated by crushing and faulting, which in places is intense. In general, however, three stages in the formation of the tactites can be detected.

The first stage consists of the addition of silicon to the dolomite, accompanied by some potassium and water. This gives rise to rocks composed essentially of diopside and phlogopite, commonly with a little tremolite. (Fig. 5).

In the second stage, sodium and aluminum were added, causing the formation of new minerals which partly replace the earlier minerals (Fig. 6). The most abundant mineral produced in this stage is oligoclase, which may form 70 percent of the rock, and the other minerals present include diopside, tremolite, phlogopite, and scapolite. This stage appears to correspond to the feldspathization and ore type metasomatism in the granodiorite (see below).

A final stage is due to addition of fluorine and tungsten, which locally formed coarse scheelite and fluorite, replacing the other minerals. This corresponds to the scheelite mineralization in the granodiorite.

A notable feature of these tactites of the second and third stages is that they contain essentially the same minerals as are found in the granodiorite ore, though the percentage of dark minerals is higher in the tactites.

Thermal Metamorphism.—The upper 50 feet of the dolomite formation, approaching the shale contact, is an argillaceous dolomite. This portion of the formation contains lenses of calc-silicate hornfels composed of garnet, epidote, diopside, and calcite with minor amounts of tremolite and occasional plagioclase.

The more pure dolomite was recrystallized and sometimes bleached white. It may contain small amounts of talc and tremolite.

Metamorphism of the shale overlying the dolomite formed a dense hornfels composed dominantly of andalusite (generally chiastolite), cordierite, biotite, muscovite and quartz.

FIG. 5. Tactite composed of diopside (di), phlogopite (ph) and scheelite (sc). Remnant of metamorphosed dolomite against granodiorite that was not removed by the thrust fault. (Plane light, × 45.)

FIG. 6. Feldspathized tactite containing oligoclase (pl), quartz (q), diopside (di) and scheelite (sc). (Plane light, × 45.)

METASOMATISM

Superficial examination of the main stock of the Illinois granodiorite indicates that most of the granodiorite is unaltered, and that metasomatic alteration is rare or absent. In the Victory Ridge region, however, widespread metasomatic alteration is associated with zones of intense shearing and crushing.

Stages of Metasomatism

Four successive stages of metasomatism in the granodiorite can be recognized, though they grade into each other, and any or all may be present in the same specimen, developed to a greater or lesser extent. The four stages recognized are: 1) Feldspathization, 2) ore-type metasomatism, 3) scheelite mineralization, 4) quartz veining.

The alteration clearly depends on fracturing and crushing of the host rock, permitting the metasomatic fluids to permeate the rock. Where the crushing was of limited intensity or duration the mechanically produced openings soon became sealed and with no further fracturing only a part of the series of replacements took place. Repeated fracturing and crushing was required for the ore-type and scheelite mineralization stages to appear.

Feldspathization.—The most important process in this stage is the replacement of quartz by feldspar. Some specimens of slightly crushed granodiorite show the replacement of a large quartz grain by an irregular intergrowth of orthoclase and plagioclase, but all that can be seen in most samples is a gradual disappearance of quartz and a corresponding increase in the amount of feldspar. It seems that at first the quartz is replaced by approximately equal amounts of orthoclase and plagioclase (orthoclase may be in excess of plagioclase). At a later stage plagioclase replaces much of the orthoclase. The large orthoclase crystals are corroded by myrmekitic oligoclase, and also commonly veins of granular myrmekitic oligoclase cut the orthoclase parallel to the shearing. This granular oligoclase gradually increases in grain size and loses the vermicular quartz inclusions, so although much of the crushed granodiorite is fine-grained, the final pr)duct of feldspathization is a coarse-grained rock composed essentially of oligoclase (Fig. 7) but commonly containing relics of orthoclase.

Accompanying feldspathization, there is a change in the dark minerals. The allanite, apatite, and zircon persist unchanged, but the dark brown biotite of the granodiorite changes to a golden brown type, and this to a very pale type with a lower refractive index. This alteration of the biotite is due to conversion of the ferriferous biotite of the unaltered granodiorite to a very magnesian, phlogopitic biotite. In many of the completely feldspathized rocks the biotite has entirely disappeared. The alteration and eventual disappearance of the biotite is accompanied by the formation of sphene, presumably formed from titanium derived from the biotite.

The main chemical changes (Table 3, No. 1, 2) during initial feldspathization of the granodiorite are a fall in silica, and a rise in alumina, sodium, and to a lesser extent, lime.

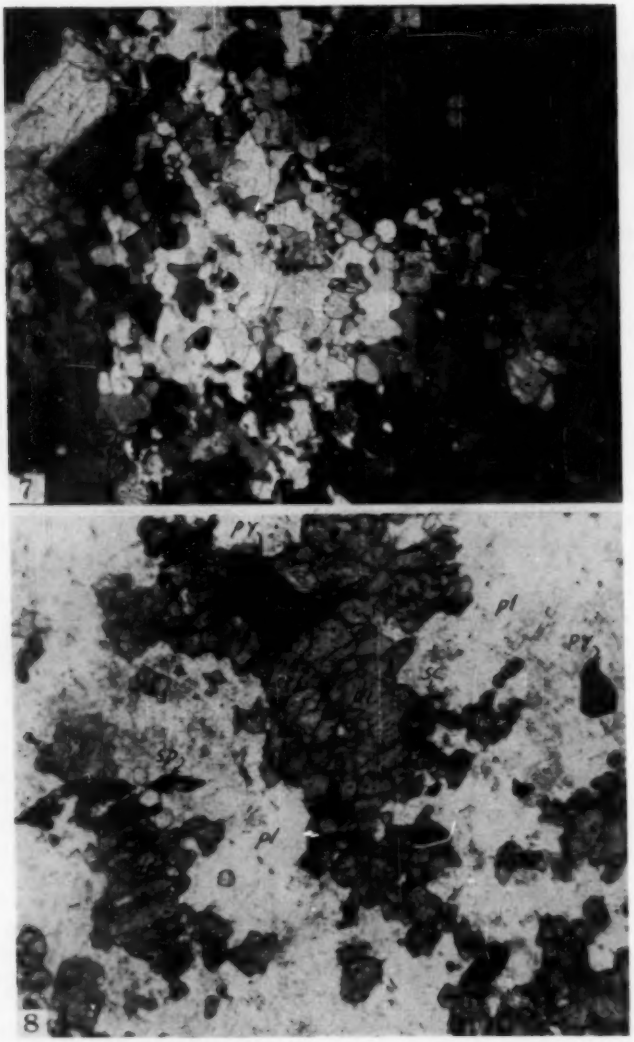
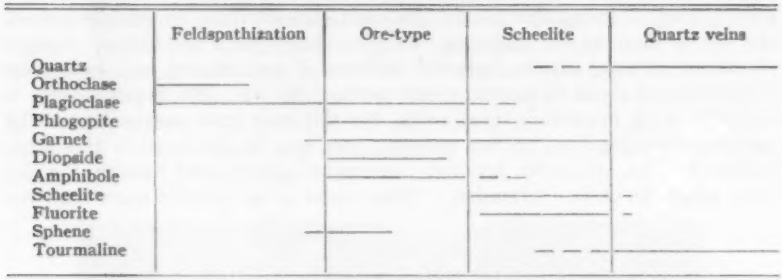


FIG. 7. Feldspathized granodiorite composed of oligoclase with scheelite. The crushed fragments of the original minerals were replaced by oligoclase and in the late stage large oligoclase crystals formed from the small ones. (X-nicols, × 45.)

FIG. 8. Feldspathized granodiorite showing the growth of diopside (di), sphene (sp), pyrite (py) and scheelite (sc) in the late stage of metasomatism. (Plane light, × 45.)

TABLE 1

THE ORDER IN WHICH THE VARIOUS MINERALS OF THE METASOMATIC STAGES WERE FORMED



Ore-Type Metasomatism.—A distinct episode of metasomatism, later than the feldspathization, is here called the ore-type metasomatism. This occurs in the more strongly feldspathized rocks, but similar effects were found in two places in granodiorite which had been only sparingly feldspathized. The ore-type metasomatism again is dependent on crushing, which permits relatively easy movement of the metasomatizing fluids, and many of the rocks that were crushed during early periods of movement were so firmly cemented during feldspathization that they were unaffected by later metasomatism. The ore-type metasomatism is thus confined to rocks that were crushed during, or shortly before, the period of activity of these fluids.

Most specimens that have been subjected to ore-type mineralization have much of the orthoclase replaced by plagioclase (Fig. 7), but locally there is not much change in the proportion of the two feldspars. The secondary plagioclase is rather variable in composition, with a range from An_{13} to An_{35}, the common value being near An_{23}. Generally the rocks from this stage are coarser grained than the feldspathized granodiorite. The most conspicuous feature in this stage is the introduction of various ferromagnesian minerals. In the less altered types these are found in veins cutting the feldspar or in

TABLE 2

MINERALOGICAL COMPOSITION OF ROCKS OF THE METASOMATIC STAGES

	Granodiorite		Feldspathized		Ore-type		Scheelite	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Quartz	33	30–35	5	0–30	5	0–10	8	0–15
Orthoclase	20	18–22	30	0–60	10	0–30	6	0–20
Plagioclase	42	40–45	62	40–95	70	50–95	77	50–95
Biotite	4	2– 5	1	0– 2	—	0– 4	—	0– 4
Diopside	—	—	—	—	—	0– 5	—	0–12
Amphibole	—	—	—	—	—	0– 2	—	0– 2
Garnet	—	—	1	0– 2	3	0– 5	4	0–10
Others	1	1– 2	1	0– 2	—	0– 2	—	0– 3

areas of relatively intense crushing, but in the more altered rocks the ferromagnesian minerals occur scattered throughout the rock, and may be seen to replace feldspar in some sections; they are probably always later than the main period of feldspathization. The most characteristic minerals produced are one or more of the following: diopside, hastingsitic amphibole, strongly pleochroic sphene, garnet (unusual mixture of grossularite and spessartite molecule, each about 42 percent), and pyrite (Fig. 8). Phlogopitic biotite is also commonly present in these rocks, but this may have survived from the earlier feldspathization. Other minerals that may be produced in this stage include epidote, sphalerite, brookite, tourmaline, calcite, and fluorite, the last three generally of late formation. These rocks never contain more than ten

TABLE 3

CHEMICAL ANALYSES

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
SiO_2	74.07	65.06	61.17	60.06	76.64	74.56	77.04	76.74
Al_2O_3	13.03	18.34	20.12	21.39	12.87	15.09	11.84	
FeO	1.58	1.40	1.46	2.88	1.04	.95	1.32	16.10
Fe_2O_3	.72	.88	.94	.03	.13	.22	1.05	
TiO_2	.22	.04	.33	.32	.12	.18	.37	
MnO	.16	.10	.26	1.42	.04	.06	—	
CaO	1.62	1.79	5.17	5.68	2.52	.22	1.28	.34
MgO	.73	.48	.76	1.02	.58	.51	.04	.10
K_2O	3.37	4.05	1.73	.43	3.92	6.58	1.64	3.99
Na_2O	3.66	5.44	6.38	5.86	1.48	.50	4.45	.58
H_2O^-	.24	.18	.16	.03	.14	.03	—	
H_2O^+	.40	1.64	.65	.19	.78	1.08	.54	
CO_2	—	—	.54	—	—		.14	
P_2O_5	.07	.09	.08	.08	—		.04	
S	—	.79	.72	.86	—			

No. 1*—Granodiorite. Victory Ridge.

No. 2*—Feldspathized granodiorite. Victory Ridge.

No. 3*—Ore-type feldspathized granodiorite. Victory Ridge.

No. 4*—Scheelite stage feldspathized granodiorite. Victory Ridge.

No. 5*—Andalusite rock in granodiorite. Victory Ridge.

No. 6*—Andalusite rock in granodiorite. Victory Ridge.

No. 7—Albitized quartz diorite. After Gilluly, Sparta, Oregon.

No. 8—Andalusite-quartz latite. After Butler, San Francisco district, Utah.

*W. H. Herdsman, Analyst.

percent dark minerals and the relative proportion of the various minerals varies greatly.

Chemically, the ore-type mineralization continues the changes found during feldspathization, except for more marked increase in calcium, and a large decrease in potassium. (Table 3, No. 3.)

Scheelite Mineralization.—The host for the scheelite is essentially the same as the product of the ore-type mineralization. In most parts of the ore the original quartz of the granodiorite is entirely replaced by oligoclase, and the orthoclase is also largely or entirely replaced. Apparently renewed crushing, or continued crushing, was required before scheelite mineralization occurred, and commonly the scheelite follows crush zones in the ore-type rock. The main feature of this stage is the introduction of scheelite, generally

accompanied by further garnet, fluorite, and less commonly, quartz (Fig. 9).

Some of the mafic inclusions in the granodiorite in the mine area have been involved in the metasomatism that gave rise to the ore, and they show changes similar to those found in the granodiorite. The originally abundant biotite is represented by subordinate phlogopite, sphene may be abundant, and the other minerals commonly associated with the ore are also found.

In general, the chemical changes during the scheelite mineralization (Table 3, No. 4) continue those found in the ore-type metasomatism, the gross composition of the two types being similar except for the introduction of fluorine and tungsten in the last stage.

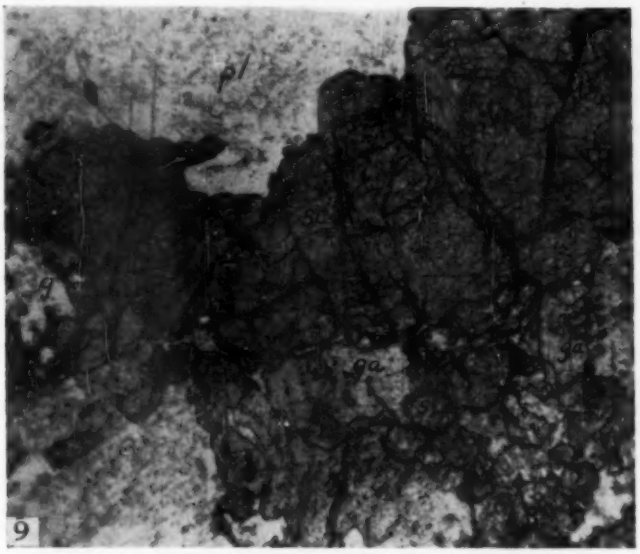


FIG. 9. Garnet (ga), scheelite (sc) and quartz (q) replacing oligoclase (pl) in feldspathized granodiorite. (Plane light, × 45.)

Quartz Veining.—Introduction of quartz seems to have been the final mineralizing process throughout the area. In the field there are many quartz veins, but in addition many of the metasomatically altered rocks contain small veinlets of quartz, commonly only visible with lens or microscope. Numerous large veins, especially the later ones or those associated with the most intense shearing, contain much black tourmaline, but only rarely do scheelite crystals occur.

The period of formation of the minerals produced during the various metasomatic changes which led up to the scheelite ore is represented diagrammatically in Table 1, and the mineralogical composition of the rocks of the various stages is shown in Table 2.

Andalusite Zone

North of the mine there is an east-west shear zone here called the andalusite zone, along which the granodiorite has been subjected to a different type of alteration. In an early stage of alteration the plagioclase breaks down, giving rise to a fine aggregate of more calcic plagioclase (it may be as calcic as about An_{50}) with quartz, orthoclase, and muscovite. Later all the plagioclase is replaced by quartz-muscovite-andalusite aggregates.

In the most altered samples from this zone much of the orthoclase is also replaced, and the final product is a rock composed essentially of quartz, muscovite, and andalusite. A characteristic feature of all rocks from this zone is the presence of subordinate tourmaline.

As seen from the analyses (Table 3, No. 5 and No. 6), the most obvious changes in the chemical composition of rock from this zone are a marked increase in potassium and a corresponding reduction in sodium and (in the later stages) calcium, together with smaller reductions of iron, manganese, and magnesium.

The feldspar relics in this zone are commonly cloudy due to alteration to sericite and clay minerals. Little of the feldspar in the feldspathized and scheelite mineralized rocks shows this retrograde effect. It thus seems probable that the alteration in the andalusite zone is later than the metasomatism in the feldspathized areas and probably took place at a lower temperature.

Structural evidence indicates that the movement on the shear planes of the andalusite zone was simultaneous with and later than the formation of the quartz veins. Thus these alteration processes in the andalusite zone, probably controlled by percolation of hydrothermal solutions along the shear planes, must have occurred later than the period of feldspathization.

No alteration similar to that in the andalusite zone was found in any other part of the granodiorite. The only other andalusite found in the area is that in the metamorphosed shale and the granitized shale.

SUMMARY OF THE GEOLOGICAL HISTORY

The geological history of the area may be summarized as follows:

(1) Emplacement of the Illinois granodiorite stock with crystallization and partial cooling to cause the development of an initial joint system.

(2) Initial application of east-west compressive forces. The main effect at this stage was the development of a zone of intense shearing, striking about north-south along the west edge of the granodiorite. The dike of fine-grained aplitic granite was intruded along a branch of this shear zone at an early stage. Some fracture zones with a northwest strike also formed at about this time. Accompanying this shearing and fracturing, which must have been recurrent, the rock was soaked by metasomatic fluids which caused first feldspathization and later the formation of the ore-type and scheelite-bearing rocks.

(3) Formation of the younger north-south shear zone and the N 10° W jointing and fracturing. This episode was accompanied by abundant deposi-

tion of quartz representing the last stage of metasomatic activity in most of the area.

(4) Intense shearing along the narrow andalusite zone in the granodiorite striking N 75° E. This shearing was accompanied by a quite distinct hydrothermal alteration which caused the formation of andalusite.

(5) Intrusion of the andesite dike which follows the N 10° W fractures for most of its course. The andesite is later than most of the fracturing and shearing, but is displaced by one of the northwest fracture zones. The northwest fracture zones appear to have been active intermittently throughout the period of compression.

(6) Culmination of the thrusting along the Dougan thrust. The thrust cuts all the structures in the granodiorite, but some of the northwest fracture zones continued to be active after the thrusting was completed.

(7) Displacement of the thrust by a steep north-dipping fault at the west end of the andalusite zone.

(8) The last stage in the igneous history was the intrusion of lamprophyre dikes which tend to follow shear and fracture zones in the granodiorite, especially the northwest fractures.

NATURE OF THE METASOMATIC PROCESS

The feldspathization of the granodiorite and the related scheelite mineralization are considered to be late magmatic or pneumatolitic processes. Late magmatic solutions filtered upward through solidified, but still very hot, granodiorite, guided by sheared and crushed zones.

Although four more or less distinct chemical stages of metasomatic replacement are recognized, there is no evidence to imply that they were formed by four distinct, or widely spaced, solution injections. Rather, the evidence points toward a continuous percolation of gradually changing solutions, because rocks of the various stages are in many instances seen to grade through a complete transition series. The different mineral facies characteristic of different stages must then have resulted from gradually changing physicochemical properties of the solutions and wall rock.

There is little sericitization, chloritization, or other typical low-temperature alteration in the feldspathized rocks. This is true whether the feldspathized mass is large or only a few inches thick along the walls of a fracture. Thus it seems that the rocks must have been nearly as hot as the volatile solutions or the latter would have cooled rapidly and there would be evidence of low-temperature alteration. Likewise no low-temperature alteration was found where crushed or pulverized granodiorite recrystallized with no change in mineral composition; i.e., no contact with metasomatizing solutions. Thus the recrystallization in the latter case must have developed entirely through the agencies of heat and locally derived, chemically unreactive, solutions. The formation of plagioclase (oligoclase or rarely andesine) in many of the metasomatically altered rocks is additional evidence that the temperatures were high during metamorphism.

No alteration was found in either feldspathized or nonfeldspathized grano-

diorite along the walls of the quartz veins, which, in so far as is known, represent the final stage of the feldspathization process. The lack of any low-temperature hydrothermal alteration of the wall rocks indicates that the quartz veins must be of high temperature origin, which is further emphasized by the abundance of tourmaline associated with them. Since there was no perceptible interchange of constituents between quartz-bearing solutions and country rock, and no alteration of the country rock, the two must have been in equilibrium. If the temperature of the wall rock was equal to that of the mineralizing solutions such equilibrium could more easily be obtained.

The cataclastic features of the granodiorite require almost complete solidification before they could have developed. On the other hand, such widespread and intense cataclasis might be more easily accomplished in a massive rock if it were still very hot or still retained a few percent of interstitial liquid. It would then be less competent and break more easily under directed stress. Further, no mylonitic material is to be seen even in the most intensely sheared rock. This holds true even where the crushed and sheared rocks were not subjected to later feldspathization processes. Thus the temperature must have remained sufficiently high to enable recrystallization of any fine material that was produced.

From the above considerations it appears probable that the shearing of the granodiorite took place shortly after consolidation and while the temperature was still high. The rather unusual type of metasomatism that apparently followed shortly after the beginning of shearing then may be in part related to the fact that the metasomatic fluids were not appreciably cooled while permeating the rock.

DISTRIBUTION OF QUARTZ

Surface mapping appears to show the presence of a definite, nearly horizontal plane of demarcation above which a large amount of quartz was deposited and below which only a small amount was deposited. This plane is near the 5400 contour in the western part of the area but is deeper along the east side. Also, the diamond drilling tends to further emphasize this. A drill hole about 200 feet north of the glory hole cut the later quartz-bearing shear zone at about the 5250 level, showing intensely sheared granodiorite but very little quartz, although this zone contains an abundance of quartz at the surface.

Not only does the quartz distribution suggest a plane of demarcation but there appears to be much less feldspathization above this plane. Even where the large quartz masses occur in the granodiorite above the 5500 elevation, the presence of which indicates intense pre-quartz brecciation and therefore areas of high permeability, there is little feldspathization in the enclosing granodiorite. The increase in quartz deposition with elevation and decrease in feldspathization suggest a probable temperature control of the two stages.

The only notable exceptions to this decrease in quartz below the 5400 level are the quartz veins found in drill holes on one or the other of the walls of aplite dikes in the hanging wall of the mine ore body and the arcuate aplite dike north of the mine. In addition, these are the only quartz veins in which

scheelite has been found. However, no field evidence was observed to indicate that this quartz is older than the ore-type metasomatism and very likely it is a part of the quartz stage of the metasomatic sequence.

The upward increase in quartz leads one to the possibility that a part of the quartz may have come from deeper feldspathized rocks in which the quartz was replaced, rather than having come entirely from rest magma differentiation. In this case, the upward moving metasomatizing solutions must have had a continual increase in silica content until such time as quartz began to precipitate. The increase in silica would come about in two ways; first, a relative increase over alumina and the alkalis because of their going out of solution to form the feldspar that replaced the quartz, and second, the actual increase in concentration resulting directly from the replacement of quartz by feldspar. If the metasomatic feldspar averages 60 percent SiO_2 then 40 percent of all replaced quartz would be added to the metasomatic solutions.

It seems a reasonable prediction that one might expect greater feldspathization and possible scheelite metasomatism, down the dip of the controlling structures, below areas of abundant quartz deposition which occurs between the 7200 N. and the 8600 N. coordinates.

CHEMICAL FEATURES

As shown by the chemical analysis (Table 3, No. 1), the Victory Ridge granodiorite might be called an oligoclase granite. The high SiO_2 content of 74 percent is more normal for granite since the average of granodiorite is about 65 percent. Likewise the low CaO of 1.62 percent is about normal for granite whereas the CaO average of granodiorite is about 4 percent. The plagioclase of this granodiorite is about An 25 while that in most granodiorite runs about An 35 to An 40.

Although the granodiorite is somewhat unusual, the metasomatic alteration of it is quite extraordinary. In fact, the authors have been unable to find reference to any deuteric or metasomatic products that have a similar mineral or chemical composition to these described here.

Perhaps the most unusual feature of the metasomatic process, aside from the abundant scheelite mineralization, is the continued increase in the CaO and Al_2O_3 content of the rock during the feldspathization process and a decrease in the SiO_2 and K_2O. The oligoclase, which is the bulk product of feldspathization, has an average composition, determined optically, of about An 23, but ranging from An 15 to An 30.

As seen in the chemical analyses (Table 3) and also in the calculated norm (Table 4), sample No. 2 follows a more or less normal feldspathization course with an increase in Na_2O and K_2O. This is the first alteration that has been noted in the field study, where feldspathization started but did not continue because of the rock being sealed off to further reaction with metasomatic solutions. The normative plagioclase in this rock has dropped in CaO to An 15. However, sample No. 3, which is a final product of the feldspathization of the ore-type stage, and sample No. 4, which is the product of the scheelite mineralization stage, show a very decided increase in CaO and Al_2O_3

and almost complete removal of K_2O. The Na_2O increased only slightly over that in sample No. 2. The plagioclase in sample No. 4 has increased in CaO to a calculated norm of An 35. The normative quartz has decreased from 34% in the granodiorite to about 8% in the scheelite stage rock. A small amount of quartz generally accompanied the scheelite mineralization stage, starting near the end of the ore-type stage forming microscopic veinlets; otherwise the normative quartz would be even less.

Samples Nos. 5 and 6 of Table 3 are from the andalusite zone. Field evidence indicates that this alteration is either contemporaneous with or younger than the quartz stage of the previously described metasomatic process. In this zone the rocks show a very decided increase in K_2O and an almost complete removal of CaO and Na_2O. In addition, there is a small increase in SiO_2 over that of the granodiorite while the alumina remains about constant. Sample No. 5 is from northeast of the glory hole where the rock had previously undergone some feldspathization. This rock contains only a small amount of andalusite and was not so thoroughly altered as was that of sample No. 6

TABLE 4

NORMS CALCULATED FROM THE CHEMICAL ANALYSES SHOWN IN TABLE 3

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Quartz	33.96	13.08	7.08	8.16	44.08	44.96
Corundum	.20	1.63	—	.92	1.63	6.73
Orthoclase	20.02	23.91	10.01	2.22	22.80	38.92
Albite	31.44	46.11	53.97	49.78	12.58	4.19
Anorthite	8.06	8.90	21.13	28.38	12.51	1.11
Diopside	—	—	1.46	—	—	—
Hypersthene	4.04	1.33	1.73	5.40	3.35	3.02
$MnSiO_3$	—	—	—	2.64	—	—
Pyrite	—	1.44	1.32	1.68	—	—
Plagioclase	An 20	An 15	An 27	An 35	An 48	An 20

which was taken near survey point F. The sericite and clay minerals in the altered feldspars of this zone are indicative of lower temperature alteration than the feldspathization period.

Butler (2) makes a note of an andalusite alteration of quartz latite in the San Francisco district of Utah. The quartz latite underwent intense hydrothermal alteration (much sericitization throughout the district) with gradual diminution of feldspar and formation of muscovite. As the feldspar further disappeared, andalusite formed but not in the earlier stages of alteration. The final product is a quartz-muscovite-andalusite rock. This mineral assemblage and the chemical analysis (Table 3, No. 8) are very similar to the rock of the andalusite zone. Butler assumes there was no addition of SiO_2 and K_2O but they increased relatively with the removal of other constituents.

DERIVATION OF METASOMATIC SOLUTIONS

Although the feldspathization process is considered to have resulted from emanations from a rest-magma differentiation, a further explanation is demanded for the unusual products that were formed.

The feldspathization, of course, suggests a process similar to albitization, and in manner it is similar, but in the probable composition of the metasomatic solutions, and in the reaction products formed, it is very dissimilar.

Gilluly (3), in his discussion of the Sparta albite granite states: "It is the universally recognized result of magmatic crystallization to concentrate in a low-freezing residual magma larger portions of the original alkalis and silica than are to be found in the magma as a whole." This is the normal trend of rest-magma differentiation and where these residual solutions come in contact with previously solidified rock it is to be expected that albitization and silicification will result. Table 3, No. 7, is an analysis of albitized quartz diorite taken from Gilluly. Here the albitized rock shows a decided increase in SiO_2, Na_2O, and K_2O, and a decrease in CaO from the original quartz diorite rock; just the opposite from samples 2, 3, and 4. Thus it is logical to assume that the increase in CaO content and decrease in SiO_2 and K_2O content of the feldspathized rocks of the Victory Mine area did not come about by reaction of the granodiorite with "normal" rest-magma solutions.

The first thing that one might suggest is an assimilation of limestone by the rest-magma, thus greatly increasing its CaO content and, by such addition, decreasing the relative amount of silica. However, although the original granodiorite magma might have had sufficient superheat to assimiliate several percent by volume of limestone, it is most doubtful that the rest-magma could do so. Likewise, such CaO increase in the original magma should have been expressed by greater CaO content of the first crystallizing minerals.

It seems unlikely that the rest-magma of this granodiorite would have had any significant difference in composition from that which is generally assumed. What, then, brought about the very decided change in the feldspathization trend (increase in CaO, decrease in SiO_2) shortly after it began? Perhaps the small outcrop of pegmatite and granitized shale, west of the mine, along with the abundance of phlogopite and diopside in remnants of contact-metamorphic rocks that were not later feldspathized, may give some possible clue to the problem.

The pegmatite is a coarse-grained quartz-orthoclase-albite-muscovite rock. Probably it is not too dissimilar in chemical composition from the supposed rest-magma that would result during solidification of this granodiorite, except for loss of volatiles. In fact, it seems even probable that this pegmatite might be a crystallized product of the granodiorite rest-magma. Evidence was cited to indicate that this material was mobile during its formation, and its intimate association with the granitized shale suggests a possible reaction between the pegmatitic solutions and the adjacent shale.

The supposed trend, here proposed, from the beginning of crystallization of the granodiorite is: first, the differentiation to a rest-magma similar in composition to the exposed pegmatite, and second, the reaction of the pegmatitic, or pneumatolitic, residue (highly volatile) with dolomite, similar to that exposed in this area, forming phlogopite and diopside. The formation of these minerals, which are present in remnants of the contact rocks (Fig. 6), should remove silica and potash from the solution and at the same time transfer lime and carbon dioxide to it. This is the concentration that is required for the feldspathization process.

and almost complete removal of K_2O. The Na_2O increased only slightly over that in sample No. 2. The plagioclase in sample No. 4 has increased in CaO to a calculated norm of An 35. The normative quartz has decreased from 34% in the granodiorite to about 8% in the scheelite stage rock. A small amount of quartz generally accompanied the scheelite mineralization stage, starting near the end of the ore-type stage forming microscopic veinlets; otherwise the normative quartz would be even less.

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Corundum	.20	1.63	—	.92	1.63	6.73
Orthoclase	20.02	23.91	10.01	2.22	22.80	38.92
Albite	31.44	46.11	53.97	49.78	12.58	4.19
Anorthite	8.06	8.90	21.13	28.38	12.51	1.11
Diopside	—	—	1.46	—	—	—
Hypersthene	4.04	1.33	1.73	5.40	3.35	3.02
$MnSiO_3$	—	—	—	2.64	—	—
Pyrite	—	1.44	1.32	1.68	—	—
Plagioclase	An 20	An 15	An 27	An 35	An 48	An 20

which was taken near survey point F. The sericite and clay minerals in the altered feldspars of this zone are indicative of lower temperature alteration than the feldspathization period.

Butler (2) makes a note of an andalusite alteration of quartz latite in the San Francisco district of Utah. The quartz latite underwent intense hydrothermal alteration (much sericitization throughout the district) with gradual diminution of feldspar and formation of muscovite. As the feldspar further disappeared, andalusite formed but not in the earlier stages of alteration. The final product is a quartz-muscovite-andalusite rock. This mineral assemblage and the chemical analysis (Table 3, No. 8) are very similar to the rock of the andalusite zone. Butler assumes there was no addition of SiO_2 and K_2O but they increased relatively with the removal of other constituents.

DERIVATION OF METASOMATIC SOLUTIONS

Although the feldspathization process is considered to have resulted from emanations from a rest-magma differentiation, a further explanation is demanded for the unusual products that were formed.

The feldspathization, of course, suggests a process similar to albitization, and in manner it is similar, but in the probable composition of the metasomatic solutions, and in the reaction products formed, it is very dissimilar.

Gilluly (3), in his discussion of the Sparta albite granite states: "It is the universally recognized result of magmatic crystallization to concentrate in a low-freezing residual magma larger portions of the original alkalis and silica than are to be found in the magma as a whole." This is the normal trend of rest-magma differentiation and where these residual solutions come in contact with previously solidified rock it is to be expected that albitization and silicification will result. Table 3, No. 7, is an analysis of albitized quartz diorite taken from Gilluly. Here the albitized rock shows a decided increase in SiO_2, Na_2O, and K_2O, and a decrease in CaO from the original quartz diorite rock; just the opposite from samples 2, 3, and 4. Thus it is logical to assume that the increase in CaO content and decrease in SiO_2 and K_2O content of the feldspathized rocks of the Victory Mine area did not come about by reaction of the granodiorite with "normal" rest-magma solutions.

The first thing that one might suggest is an assimilation of limestone by the rest-magma, thus greatly increasing its CaO content and, by such addition, decreasing the relative amount of silica. However, although the original granodiorite magma might have had sufficient superheat to assimiliate several percent by volume of limestone, it is most doubtful that the rest-magma could do so. Likewise, such CaO increase in the original magma should have been expressed by greater CaO content of the first crystallizing minerals.

It seems unlikely that the rest-magma of this granodiorite would have had any significant difference in composition from that which is generally assumed. What, then, brought about the very decided change in the feldspathization trend (increase in CaO, decrease in SiO_2) shortly after it began? Perhaps the small outcrop of pegmatite and granitized shale, west of the mine, along with the abundance of phlogopite and diopside in remnants of contact-metamorphic rocks that were not later feldspathized, may give some possible clue to the problem.

The pegmatite is a coarse-grained quartz-orthoclase-albite-muscovite rock. Probably it is not too dissimilar in chemical composition from the supposed rest-magma that would result during solidification of this granodiorite, except for loss of volatiles. In fact, it seems even probable that this pegmatite might be a crystallized product of the granodiorite rest-magma. Evidence was cited to indicate that this material was mobile during its formation, and its intimate association with the granitized shale suggests a possible reaction between the pegmatitic solutions and the adjacent shale.

The supposed trend, here proposed, from the beginning of crystallization of the granodiorite is: first, the differentiation to a rest-magma similar in composition to the exposed pegmatite, and second, the reaction of the pegmatitic, or pneumatolitic, residue (highly volatile) with dolomite, similar to that exposed in this area, forming phlogopite and diopside. The formation of these minerals, which are present in remnants of the contact rocks (Fig. 6), should remove silica and potash from the solution and at the same time transfer lime and carbon dioxide to it. This is the concentration that is required for the feldspathization process.

It should be mentioned that the common process of albitization of igneous rocks should free Ca ions from altered plagioclase. This calcium, if not entering into the formation of some other mineral, such as epidote, should be incorporated in the reacting solution and thus bring about the desired result. But, albitization has been described from a great number of places and no similar calcic metasomatic reactions in the vicinity of the albitized rocks are mentioned.

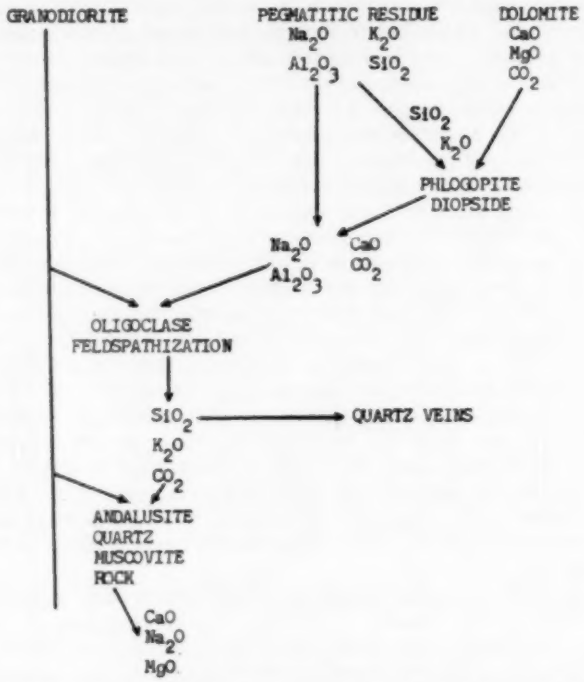

FIG. 10. Diagram showing possible products formed by reaction between pegmatitic residue and dolomite; the residual solution which in turn reacted with the granodiorite; and the products of the latter reaction.

Figure 10 is a diagrammatic sketch on which the various required reaction results are shown, starting with a reaction between a volatile pegmatitic residue and a dolomite. SiO_2 and K_2O from the pegmatitic residue react with dolomite to form phlogopite and diopside. As previously stated, these two minerals are the dominant ones found in unaltered remnants of the tactite. The formation of phlogopite takes up K_2O while both minerals take up SiO_2. CaO is freed by the formation of phlogopite. In the absence of any associated

secondary calcite or dolomite crystals it can be assumed that at least a part of the calcium entered the mobile phase, which then, together with the Na_2O and Al_2O_3 from the pegmatitic residue, moved on to react with the granodiorite. The replacement of quartz and orthoclase in the granodiorite by oligoclase in turn freed to the solution the SiO_2 and K_2O needed for the quartz veins and the andalusite alteration. As shown, the andalusite alteration is considered to be a later and lower temperature reaction than the feldspathization process, but probably formed by hydrothermal solutions from the same source and subjected to similar reactions as they ascended. Figure 11 is a ternary diagram of normative quartz, orthoclase and plagioclase (albite plus anorthite) showing first, the change in the granodiorite during the feldspathization (numbers 2, 3, and 4), and second, the change during the andalusite alteration (numbers 5 and 6).

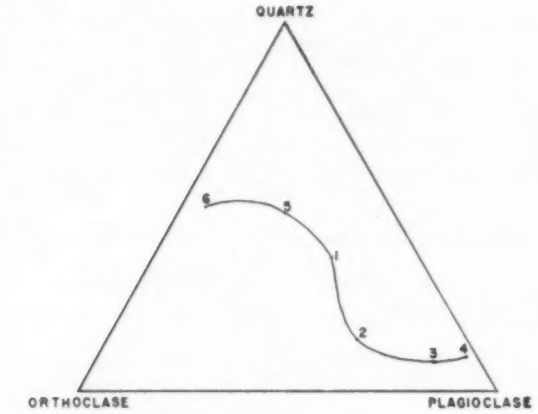

FIG. 11. Ternary diagram showing, first, the change in the granodiorite during the feldspathization (numbers 2, 3, and 4), and second, the change during the andalusite alteration (numbers 5 and 6).

It is interesting to note that the products concentrated in the solution from the oligoclase reaction are the same ones that were depleted by reaction with the dolomite, and those produced from the andalusite reaction are the same ones that were needed to bring about the oligoclase reaction.

For conditions suitable to the first reaction shown in Figure 10, the authors envision a block of dolomite or shaly dolomite, perhaps a stoped block contained in the granodiorite and so situated that the metasomatic solutions could have easy access to it. This is more feasible than a contact reaction where the solutions must first have moved out of the granodiorite and then returned. The above reacting materials and products formed are all found within the area and were not chosen arbitrarily.

SCHEELITE MINERALIZATION IN THE VICTORY MINE

The ore body in the Victory Mine (Fig. 12) occurs in a feldspathized zone striking about N 5° to 10° W and dipping between 40° and 50° W. Information from drill holes and mine workings indicates that the feldspathized zone exceeds 350 feet in length along the shear zone, extends over 300 feet down the dip, and varies between 10 and 40 feet in width normal to the dip. The ore zone, however, occupies only a portion of the feldspathized zone. The ore is gradational with the feldspathized rock and is fairly well outlined as an inverted triangular body about 150 feet long on the upper level of the mine (5260 level) and tapering to about 30 feet at the bottom. The height of the triangle is approximately 300 feet.

The scheelite deposition appears to have been controlled by the following favorable features: (1) early shearing along the hanging wall side, striking

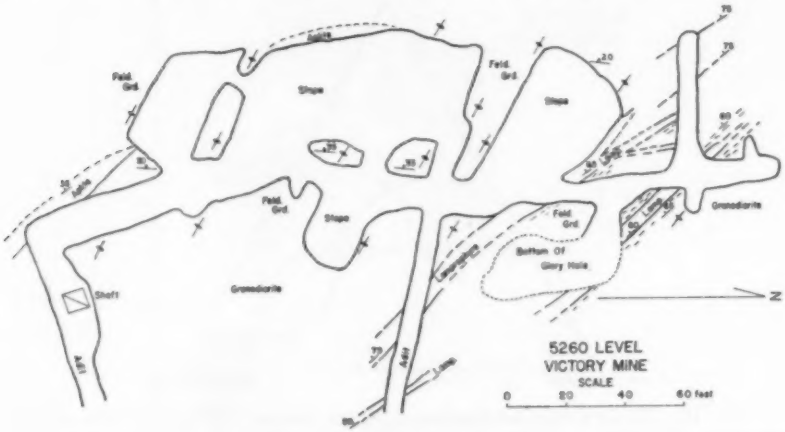

FIG. 12.

about N 10° W and dipping 40° to 50° W; (2) early shearing along northeast side, striking about N 40° W with a 50° to 70° southwest dip; (3) crushing of rock in the triangle between the converging shears; (4) intrusion of aplite within the north 10° west shear zone; (5) recurrent movement along N 10° W shear zone; and (6) strong N 50° W vertical jointing localized within the feldspathized granodiorite. This jointing occurred after the feldspathization stage and appears to have permitted continued percolation of metasomatizing solutions following that stage.

The shortening of the ore body with depth gives it the shape of an inverted right triangle. The southern limit of the ore body is about vertical and parallel to the strong N 50° W jointing. The feldspathized rock to the south of the ore body is well exposed in the shaft and in the pocket cross-cut of the 80-level (80 feet below the upper level); the rock differs from the ore by a

lack of strong jointing and crushing following the feldspathization. The northern limit of the ore in the upper level is the north 40° west shear zone and the pitch of the northern edge of the ore down to the 300 level is about 60°, which almost parallels the dip of the shear zone. Thus, the northern edge of the ore seems to be structurally defined but there is no clear explanation for the vertical localized jointing in the feldspathized zone.

All the rock within the ore body is feldspathized but there are two prominent pillars, between five and ten feet wide, within the ore zone on the upper mine level (Fig. 12) that were not sufficiently enriched to be ore. They parallel the local N 50° W jointing and extend completely across the width of the ore. Megascopic and microscopic examination shows that they were not so intensely jointed and crushed as the rocks on either side and therefore remained impervious to further metasomatism, as did the rock south of the ore body.

The N 10° W early shear zone seems to be the hanging wall of the ore down to the bottom mine level. This zone accommodates aplite dikes, and aplite seems generally to cap strongly feldspathized rock. Examination of drill cores from the hanging wall of the ore body shows that there are a number of aplite dikes in different parts of the shear zone. In most cases ore-type metasomatism and scheelite mineralization have taken place directly below the aplite. The following log of a portion of a diamond drill hole provides a good example of this.

Depth	Log	Thin Section Description
104–107	Aplite	
107–108	Banded gray-green ore	Ore-type. Strongly feldspathized. Orthoclase-free, with garnet and phlogopite.
108–110	Aplite	
110–123	Granodiorite	116 ft. Slightly crushed and feldspathized. Some actinolite.
123–135	Fine-grained granodiorite and banded aplite	
135–139	Ore material	137 ft. Ore-type. Strongly feldspathized. Orthoclase-free. Contains scheelite, garnet, fluorite, and phlogopite.
139–142	Aplite and quartz	
142–146	Ore material	
146–154	Banded granodiorite and aplite	147 ft. Crushed and feldspathized granodiorite.
154–195	Ore material. (This is the mine ore body.)	158 ft., 164 ft., 168 ft., 178 ft., 188 ft. Ore strongly feldspathized. Orthoclase-free. Scheelite, garnet, fluorite, diopside, and phlogopite.

An older and mostly obliterated joint set, striking about north-south and dipping 20 to 40° W, seems in places to have aided in either guiding or confining the mineralizing solutions. This is noticeable in places at one or the other of the walls where the ore appears to descend in steps.

The later north-south, quartz-bearing shear zone, west of the mine, does not seem to have helped to control the metasomatic processes. In fact, the only feldspathized rocks found within this later shear zone are also sheared, which suggests that the north-south shear zone is younger than the feldspathization stage. This lack of recementing by feldspathization in the later shear zone is probably the reason it permitted such widespread impregnation by quartz whereas the older adjacent shear zones did not.

There are other potential ore bodies within the area but since these are only now being explored or are not yet mined out, the authors do not feel free to discuss them.

STANFORD UNIVERSITY,
STANFORD, CALIFORNIA,
June 18, 1957

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MINERALS OF THE CASSITERITE-BEARING VEINS AT IRISH CREEK, VIRGINIA, AND THEIR PARAGENETIC RELATIONS [1]

JEWELL J. GLASS, A. H. KOSCHMANN, AND J. S. VHAY

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ABSTRACT

Major rock types of the Irish Creek district are gneisses and schists, intruded by granodiorite. All these rocks are believed to be Precambrian. The ore deposits are fissure veins consisting largely of quartz veins bordered by greisen, and enriched by recurrent deposition.

From field and microscopic evidence six stages of mineral formation have been deduced:

1. Crystallization of the granodiorite with the formation of hypersthene, augite, hornblende, andesine, orthoclase, microcline, and quartz; and accessory apatite, rutile, ilmenite, titanomagnetite, and zircon.
2. Metamorphism of the granodiorite and gneiss with formation of uralitic actinolite, epidote, and sphene.
3. A period of fracturing and formation of quartz veins.
4. Greisenization of the host rock producing first: coarse muscovite, brown biotite, cassiterite, beryl, wolframite, and quartz; then producing a second group of minerals—fluorite, green biotite, chlorite, *phenakite*, siderite, *ankerite*, *parisite*, *sphalerite*, sulfides, including *aikinite* and *galenobismutite*, leucoxene, fine muscovite, and quartz.
5. Formation of late vein minerals, *clinozoisite*, calcite, nontronite, and *montmorillonite*.
6. Formation of surficial alteration products, kaolinite, *vermiculite*, hematite, limonite, and *scorodite*.

The italicized mineral names indicate the minerals heretofore unreported from Irish Creek; parisite, aikinite, and galenobismutite are new minerals for Virginia. Included in the detailed descriptions of all the minerals is a chemical analysis of beryl.

[1] Publication authorized by the Director, U. S. Geological Survey.

INTRODUCTION

THE existence of cassiterite-bearing veins in the Irish Creek district of Virginia has been known for more than 100 years. Although cassiterite from this area was identified in 1846 (7), no exploration was done until a specimen

TABLE 1

NAMES AND OCCURRENCE OF THE NONOPAQUE MINERALS FROM THE PANTHER RUN TIN DEPOSITS, IRISH CREEK, VIRGINIA, DETERMINED BY J. J. GLASS

Name	Remarks
Actionolite (Uralite)	Firbrous amphibole replacing pyroxene in metamorphosed granodiorite.
Andesine	Primary plagioclase in country rock; generally fractured and sericitized.
*Ankerite	Crystal aggregates in carbonate vein with siderite and fluorite; in greisen.
Apatite	Fluor-apatite variety; accessory in country rock; relict in greisen.
Augite	Primary pyroxene in country rock; as lath-shaped crystals.
Beryl	Low-alkali variety associated with quartz and fluorite in greisen.
Biotite (brown)	Abundant in greisen.
Biotite (green)	Abundant in greisen, associated with chlorite.
Calcite	In late veinlets.
Cassiterite	Fractured crystals and massive; in greisen and in fractured quartz vein.
Chlorite	Fibrous alteration product of biotite in greisen.
*Clinozoisite	In late calcite veinlets as thin elongate crystals.
Epidote	In metamorphosed granodiorite and as relicts in greisen.
Fluorite	Common in greisen.
Hematite	Rare as alteration product of magnetite; present in oxidized zone ("limonite").
Hornblende	Primary in granodiorite.
Hypersthene	Principal pyroxene in granodiorite.
Kaolinite	Earthy alteration product replacing feldspar and other silicates.
Leucoxene (Rutile?)	Fine-grained alteration product of ilmenite; relict in greisen.
Microcline	Feldspar in metamorphosed (?) granodiorite.
*Montmorillonite	Waxlike bands in shear zone in granodiorite.
Muscovite	Most abundant mineral in greisen.
Nontronite	Platy and fibrous, late mineral in greisen.
Orthoclase	Primary feldspar in granodiorite; generally altered.
**Parisite	Rare transparent grains in greisen associated with fluorite and other carbonates.
*Phenakite	Elongated crystals in greisen associated with chlorite; replaces beryl.
Quartz	Present in granodiorite, in veins, and in greisen.
Rutile	Accessory in granodiorite and as relict in greisen.
Scheelite	Rare, with wolframite in greisen and veins.
*Scorodite	Encrustation on arsenopyrite in oxidized zone.
Siderite	In greisen and in carbonate veins.
*Sphalerite	Rare in greisen.
Sphene	Rare in metamorphosed country rock.
Tourmaline	Rare in fractures in cassiterite.
*Vermiculite	Late alteration product of biotite, associated with nontronite.
Wolframite	Fine grained, as veinlets in mica and fluorite. Rare.
Zircon	Accessory in granodiorite and as relict in greisen.
Zoisite	Prismatic crystals in late calcite vein.

* Minerals described for the first time from this locality.
** Mineral described for the first time from Virginia.

discovered in 1883 (1) by Mrs. Martha D. Cash on her property was identified as cassiterite. During the period between 1883 and 1893, and again in 1918–19, several attempts were made to produce tin commercially. Because of litigation over the ownership of property no further work was done between 1919 and 1942.

In 1938 a detailed study of the accessible workings with special attention to the mode of occurrence of cassiterite and its associated minerals was made by the U. S. Geological Survey. Some of the results of that work, including a geologic map of the immediate area, and an underground map of No. 1 workings, are given by Koschmann and others (6). Although a study of the minerals and their paragenetic relations in the veins was made at that time, these data were regarded as not essential to the economic possibilities of the project and they were omitted from the published report. Renewed interest in the Irish Creek deposits, especially in the occurrence of beryl in the veins,

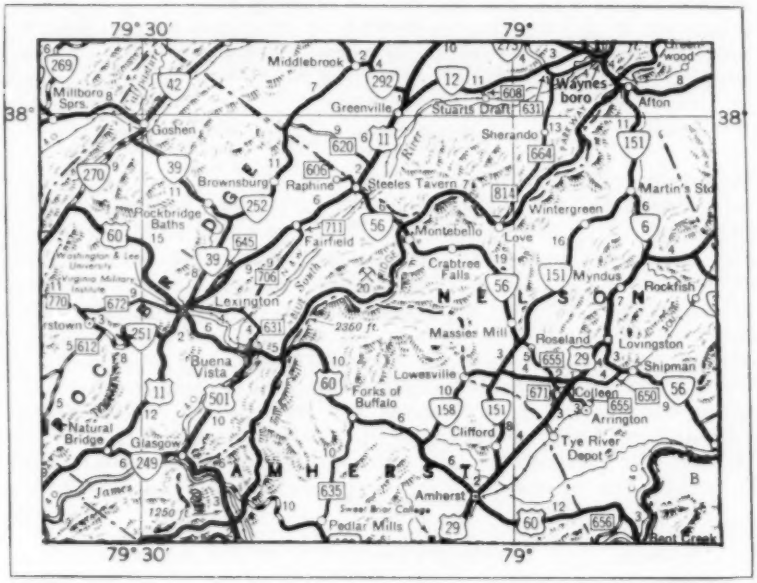

FIG. 1. Map of part of the state of Virginia, showing the location of the Irish Creek tin deposits, in Rockbridge County. (Courtesy of American Automobile Association of Washington, D. C.) Mine indicated by crossed handles of pick and hammer.

and in the unusually large assemblage of minerals has led to the desirability of publishing these mineralogical data.

Twenty or more papers have been written on the Irish Creek district, primarily on the tin deposits and the regional geology. None of these publications contains a systematic description of the mineralogy of the deposits.

The purpose of this paper is to present a description of the minerals found during the detailed study of the economic geology of the Irish Creek district and a discussion of the paragenetic relationships of the individual minerals.

Forty-six minerals have been identified from the Irish Creek tin deposits. Thirty-seven of these are nonopaque (Table 1), and nine are opaque (Table

2). Ten of these minerals are described from this district for the first time, and three of these are here described for the first time from Virginia.

We gratefully acknowledge helpful suggestions from H. G. Ferguson, F. C. Calkins, and W. C. Smith, of the U. S. Geological Survey, who critically read the original manuscript.

LOCALITY

The Irish Creek district, Rockbridge County, Virginia, is in the central part of the Blue Ridge near the boundary line of Amherst and Nelson Counties (Fig. 1). The district is about 10 miles southeast of Steeles Tavern, the

TABLE 2

PROPERTIES AND OCCURRENCE OF THE OPAQUE MINERALS OF THE IRISH CREEK TIN DEPOSITS, IRISH CREEK, VIRGINIA

Mineral	Distinctive character	Occurrence
**Aikinite	Metallic luster; yellow tarnish	With galenobismutite in carbonate veins
Arsenopyrite	Metallic luster Twinning. Brittle	Veins in quartz and greisen
Chalcopyrite	Metallic luster; iridescent. Brittle	In siderite vein
Galena	Bright metallic luster	Grains in greisen
**Galenobismutite	Metallic luster; iridescent. Flexible	With aikinite in carbonate veins and in muscovite
Ilmenite	Submetallic	Grains in greisen and granodiorite
Pyrite	Glistening metallic luster. Hard	Veins and grains in quartz
Pyrrhotite	Metallic luster; tarnish iridescent	With chalcopyrite and sphalerite
Titanomagnetite	Metallic. Strongly magnetic	Grains in greisen and granodiorite

** Minerals described for the first time from Virginia.

nearest village of any size, on U. S. Highway 11, about 15 miles northeast of Lexington. A well-graded dirt road leads from Highway 11, on the west, to the crest of the Blue Ridge where it joins the new Blue Ridge Parkway which passes directly through the area containing the tin deposits. There is also a road from the east up the Tye River valley and another from the southwest.

The Blue Ridge in this vicinity is rugged. The highest point is about 3,500 feet above sea level. The floor of the Irish Creek valley is about 2,000 feet above sea level, and is nearly level and somewhat open, unlike the densely wooded hillsides.

The veins studied are exposed on the east and west side of Panther Run,[2] a small tributary of Irish Creek. The accessible workings, referred to as No. 1 workings, consist of an open tunnel on the east side of Panther Run. The No. 2 workings on the west side of Panther Run are somewhat more extensive, but are caved.

GEOLOGY

The major rock types in the Blue Ridge region in this vicinity are gneisses and schists, intruded by granodiorite. All these rocks are believed to be Precambrian. The Precambrian rocks have been cut by a few later aplite and basic dikes (Fig. 2). The granodiorite is the host rock of the mineral deposits.

A more detailed description of the geology and petrology of the area is given by Ferguson (2) and Koschmann and others (6). The most complete bibliographies of the early literature are given by Watson (9), Hess (3), and Ferguson (2).

CHARACTER OF DEPOSITS

The descriptions presented here are believed to apply to all tin-bearing deposits in the Irish Creek district, although the details set forth in this paper were obtained chiefly from the study of the deposits exposed in the No. 1 group of workings (6). These deposits are essentially branching veins, which vary somewhat from place to place both in character and mineral composition. Typically, they consist of one or more quartz veins bordered by greisen. The veins vary in width from mere stringers to irregular masses 5 feet or more in width (6, Pl. 43). The relative proportion of the quarts and greisen is variable, but in most places, the greisen is in excess of the quartz, and locally quartz is absent. The quartz veins are true fissure veins, but the greisen formed afterward in part as replacement of the quartz veins. The lodes thus are a product of recurrent deposition following recurrent fracturing that has produced an intergrowth of minerals of late stages of deposition with minerals of earlier stages.

PARAGENESIS OF THE MINERALS

Although the age relations are not clear concerning the less abundant minerals that form only a few scattered grains in the greisen and veins, field evidence and microscopic study reveal a definite succession in mineral deposition. The several periods of deposition alternated with periods of fracturing, and the minerals formed in each stage are distinguishable in part by differences in degree of deformation. Besides undergoing shearing, the minerals of the earliest stages of deposition have been partly replaced by some of the younger minerals to such an extent that age relations among the older minerals have been somewhat obscured. Some minerals also are so closely associated that a contemporaneous origin is indicated. The sequence of mineral formation given below is believed to be essentially correct and is supported by fairly good evidence, such as difference in degree of deformation, cross-cutting veinlets, pseudomorphs, and residual structures. Some of these relations can be

[2] Called Painter Branch in the early literature.

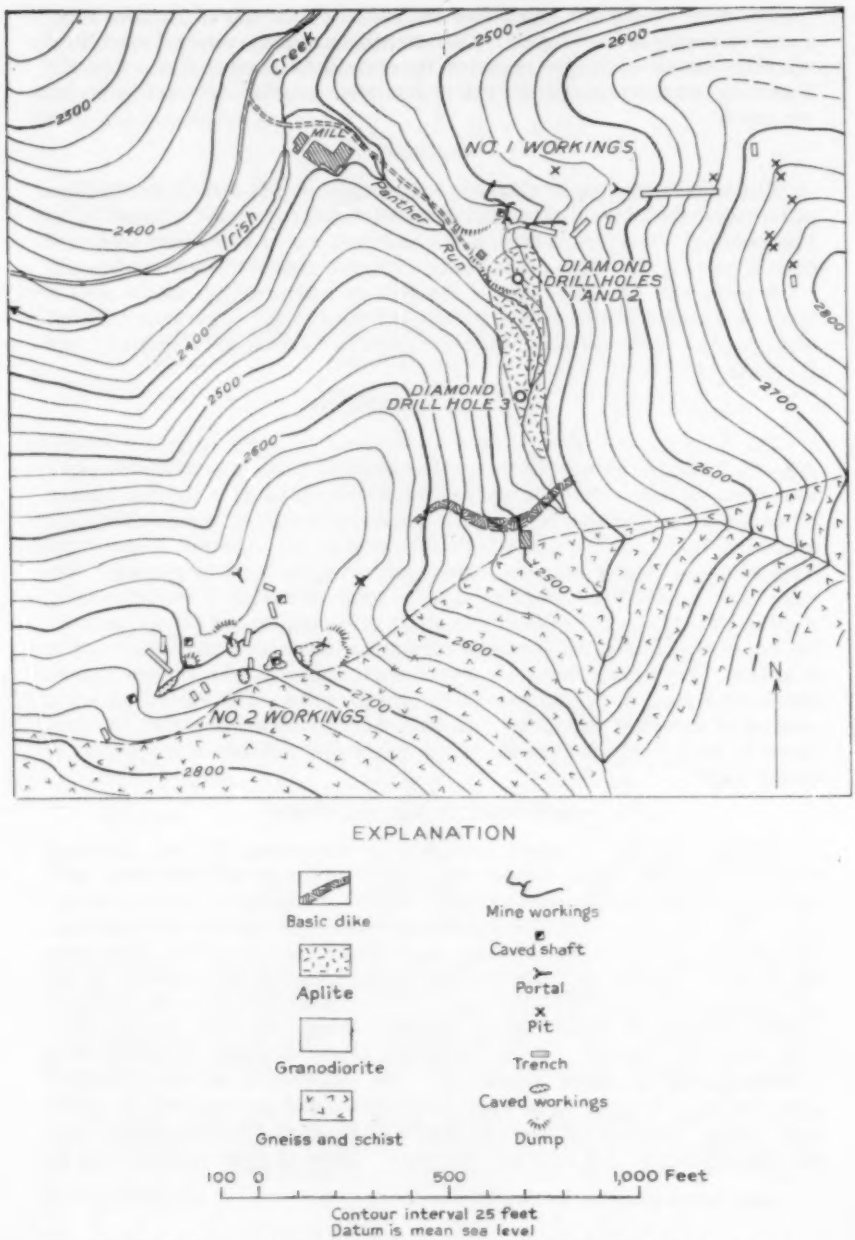

FIG. 2. Geologic map of the Panther Run area of the Irish Creek district showing location of the mine workings and prospect pits.

TABLE 3

PARAGENETIC OUTLINE FOR PANTHER RUN TIN DEPOSITS, IRISH CREEK, VIRGINIA

Mineral	Granodiorite or gneiss	Metamorphosed granodiorite	Quartz vein	Greisen		Late veins	Surficial alteration
				1st stage	2nd stage		
Quartz	X		X	X			
Orthoclase	X						
Microcline		X					
Andesine	X						
Hornblende	X						
Augite	X						
Hypersthene	X						
Apatite	X						
Ilmenite	X						
Rutile	X						
Titanomagnetite	X						
Zircon	X						
Epidote		X					
Actinolite		X					
Sphene		X					
Biotite				X	X		
Beryl				X			
Cassiterite				X			
Tourmaline				X			
Wolframite				X			
Muscovite				X	X		
Fluorite					X		
Ankerite					X		
Siderite					X		
Parisite					X		
Phenakite					X		
Chlorite					X		
Scheelite					X		
Leucoxene					X ?		X ?
Sulfides					X		
Calcite						X	
Clinozoisite						X	
Zoisite						X	
Montmorillonite						X	
Nontronite						X	
Kaolinite							X
Hematite							X
Scorodite							X
Vermiculite							X

seen in the field and others only under the microscope. The relations are summarized in Tables 3 and 4. The following stages of mineral formation have been deduced; those from stages 3 to 5 are separated by periods of fracturing or recurrent movement.

1. Crystallization of granodiorite; formation of mafic minerals (hypersthene, augite, and hornblende), feldspars (andesine, orthoclase, and possible

TABLE 4

TENTATIVE GENETIC OUTLINE FOR THE PANTHER RUN TIN DEPOSITS, IRISH CREEK, VIRGINIA

Granodiorite	Metamorphic rock	Quartz veins	Greisen		Late veins	Surficial alteration
			1st stage	2nd stage		
Augite, Hornblende, Hypersthene (Mafic minerals)	Actinolite		Brown biotite	Chlorite Pyrite Siderite	Nontronite Clinozoizite	Hematite
Andesine, Orthoclase (Feldspars)	Epidote Microcline(?)		Coarse muscovite	Green biotite Ankerite Fine muscovite (recrystallized?)	Zoisite Calcite	Vermiculite Kaolinite
Quartz		Quartz	Quartz (recrystallized)			
Apatite Ilmenite Rutile(?) Titanomagnetite Zircon (Accessory minerals)	Rutile(?) Sphene			Leucoxene (?)		Leucoxene(?)
			Beryl Cassiterite Tourmaline Wolframite	Phenakite Scheelite Fluorite Parisite Arsenopyrite Other sulfides		Scorodite
(Material passing through or added)		SiO_2, H_2O	H_2O, B, Sn, Be, W	H_2O, CO_2, F, S, As, Bi, Ce group, Cu, Zn, Pb	H_2O, CO_2	H_2O, O_2

microcline), quartz, and the accessory minerals (apatite, rutile, ilmenite, titanomagnetite, and zircon). The accessory minerals resistant to replacement are found as relict minerals among the later stage minerals.

2. Metamorphism of granodiorite and gneiss; formation of actinolite (uralite), epidote, and sphene; possibly microline belongs here also as a conversion from orthoclase.

3. Formation of massive quartz veins.

4. Formation of greisen.

a. First stage: coarse muscovite, brown biotite(?), cassiterite, beryl, wolframite, and quartz.

b. Second stage: fluorite, green biotite, chlorite, phenacite, siderite, ankerite, parisite, sulfides, leucoxene(?), fine muscovite and quartz (both probably by recrystallization).

5. Formation of late veins: clinozoisite, calcite, nontronite, and montmorillonite.

6. Surficial alteration: kaolinite, vermiculite, hematite (limonite), scorodite, and other oxidation products not listed in the tables.

MINERALS OF THE GRANODIORITE

Little discussion is believed necessary of the essential minerals in the fresh granodiorite, the country rock of the tin deposits. Notes on occurrence of andesine, orthoclase, microcline, hypersthene, augite, and hornblende are given in Table 1. Some normal alteration products of these minerals are present almost everywhere, but as the veins are approached the amount of alteration increases until the original minerals are largely unrecognizable.

The accessory minerals, apatite, ilmenite, rutile, titanomagnetite, and zircon, on the other hand, are more resistent to replacement, are found in the greisen commonly occurring together in clusters, a mode of occurrence similar to that in the granodiorite, where these accessory minerals are commonly clustered with the mafic minerals. The accessory minerals, or pseudomorphs after them, are described below:

Apatite.—Apatite is a common constituent both of the granodiorite and of the greisen which has replaced the igneous rock. In the granodiorite it is generally concentrated with the mafic minerals; and in the greisen it is present clustered with the other accessory minerals. The optical properties coincide with those for fluor-apatite.

Zircon.—Zircon is present as small elongated tetragonal crystals in the granodiorite and, as a relict mineral, in the greisen (Table 1); like many of the accessory minerals it is commonly grouped in clusters in both rocks.

Titaniferous minerals.—The titaniferous minerals ilmenite, leucoxene (rutile?), rutile, sphene, and titanomagnetite are all found in either the country rock or in the greisen; they are most commonly seen in the concentrates from the greisen. It is believed that ilmenite, titanomagnetite, and possibly rutile are original accessory minerals, although the rutile is probably more common in the metamorphic rock. The sphene is apparently formed in the meta-

morphic rock from ilmenite or titanomagnetite. The "leucoxene" is an alteration product of the older titaniferous minerals fairly common in the greisen, and was probably formed during the second stage of the greisenization (described below).

The minerals formed by the regional metamorphism of the country rock are epidote, actinolite, and probably sphene, and microcline. Epidote is rare in the mineralized zone but is abundant in a rock that is known in this region as unakite (8); it is a pale yellow variety, colorless in thin fragments. When found in the greisen it is probably a relict mineral, as are actinolite and sphene.

MINERALS OF THE QUARTZ VEINS

The quartz veins are rather irregular and branching and are generally 3 to 8 inches thick; they pinch and disappear, or widen out to more than a foot in places, especially at intersections. At the No. 2 workings they are considerably wider; a single quartz vein as much as 9 feet wide was described by W. Spencer Hutchinson, Mining Engineer, Irish Creek Tin Mines, Inc., Boston, Mass. In many places they are much fractured and crisscrossed by greisen, which locally has almost completely replaced them leaving only irregular inclusions of quartz in the greisen.

Field relations clearly show that the quartz that forms the core of the veins in the district was the first vein mineral to be deposited. In many places the quartz has been shattered, and all quartz, even that in the massive central core, shows strain shadows under the microscope. Under pressure and quartz has been granulated; in the hand specimen it is fine grained and even resembles chalcedony in places. A crude cleavage simulating a slaty cleavage has resulted from extreme shearing. Where the quartz core is solid it is barren of the later minerals.

Small amounts of quartz in veinlets cutting cassiterite and beryl and later minerals are also present and presumably are recrystallized older quarts; by itself this later stage of quartz cannot be distinguished from the earlier stage of quartz, except by its relations to other minerals.

MINERALS OF THE GREISEN

The greisen is dark gray to dark green (Fig. 4), and most of it is fine grained. It forms veins or bands 1 inch to 5 feet in thickness. It most commonly accompanies quartz veins, but locally quartz veins are absent and in other places quartz veins occur without the greisen. Where both occur, the greisen generally is thicker than the quartz, but the relative thickness of the two differs greatly from place to place.

The greisen in the Irish Creek district varies from place to place both in composition and in texture. As already pointed out, the minerals in the greisen were deposited in two stages apparently separated by a period of fracturing. The older group of minerals in the greisen includes cassiterite, beryl, coarse muscovite, a little tourmaline, and probably wolframite and brown biotite, and the younger group of minerals includes relatively fine-grained muscovite, siderite, ankerite, parisite, leucoxene, sulfides, fluorite,

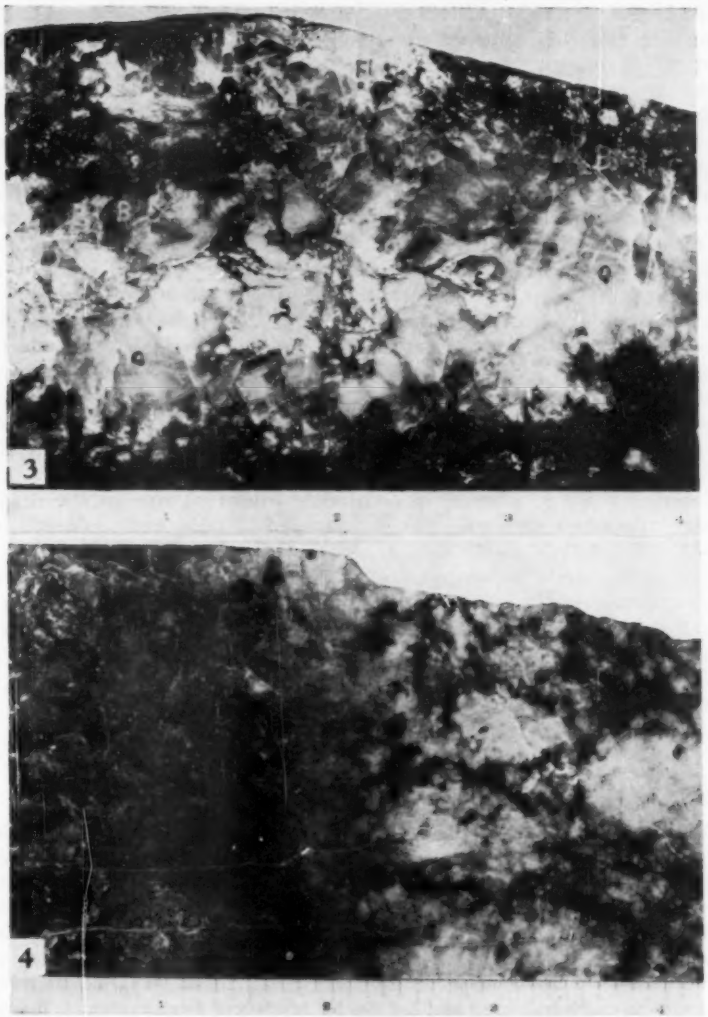

FIG. 3. Polished surface showing quartz vein in greisen. Later minerals replacing quartz are fluorite (Fl) and siderite (S). Beryl crystals (B) form irregular zones between the quartz and chlorite (black) and penetrate into the quartz (Q) and into the chlorite. Scale in inches.

FIG. 4. Polished surface showing the dark greisen zone (left) grading into the coarse-grained granodiorite. The greisen consists of muscovite, fluorite, carbonate, and cassiterite. The granodiorite consists largely of feldspar, quartz, and pyroxene. Scale in inches.

green biotite, phenakite, scheelite, and chlorite. The solutions depositing the two stages of greisen apparently were of somewhat different type and brought in different elements, as is indicated on the bottom part of Tables 3 and 4, which are tentative genetic outlines proposed for all the minerals listed in Table 1 and Table 2.

Whereas the quartz very probably filled fissures, the greisen has formed principally by the replacement of the granodiorite along the walls of the quartz veins (Fig. 4) and partly by replacement of the quartz veins themselves. Although it is not possible to identify definitely the greisen formed by replacement of granodiorite where all feldspars and pyroxenes have been destroyed, it is believed that the presence of zircon, apatite, ilmenite, and titanomagnetite (now mostly leucoxene) is a strong indication of such a replacement. Specimens of greisen from the walls of the veins, believed to have been formed by replacement of the quartz, do not show these minerals, whereas on the other hand, those from the transition zone of greisen and altered granodiorite, showing some altered but still recognizable feldspar, do contain zircon, apatite, ilmenite, and titanomagnetite, or leucoxene. Additional evidence that these minerals are residual is the fact that the apatite, the titanium mineral, and to a less extent the zircon, most commonly occur together as clusters, a mode of occurrence similar to that in the original granodiorite where they are generally clustered with the mafic minerals, and that they have in general the same habit as in the granodiorite.

Opaque minerals, mostly sulfides, in the Irish Creek deposits are few and their total amount is small. Some sulfides, as those of bismuth, occur in veinlets in the greisen and carbonate masses or along cleavage planes in muscovite, and are clearly among the last minerals in the greisen to be deposited. The paragenetic relations of some sulfides is not clear, but all the sulfides apparently belong to the younger group of greisen minerals.

First Stage Minerals of the Greisen

Muscovite.—Muscovite is the most common mineral in the greisen. It consists of coarse flakes (Fig. 5) as well as aggregates of fine flakes, and evidence at hand indicates that the muscovite is of two generations. Optically both are the same. The coarse flakes are most commonly contorted and both cassiterite and beryl cut across such large flakes. One thin section shows granular cassiterite in elongated lenses, and beryl crystals cutting diagonally across the muscovite cleavage. On the other hand, nowhere was any clear-cut evidence found of coarse mica cutting either cassiterite or beryl, although both minerals are much fractured and are cut by veinlets of fine muscovite, fluorite, and biotite. This age difference is also suggested by the absence of contortions in the finer muscovite.

Biotite.—A reddish brown biotite is common in the greisen. It may have formed during the first stage of formation of the greisen by replacement of the mafic minerals in the granodiorite. Replacement of the mafic minerals is suspected because this type of biotite is commonly associated with clumps of the accessory titaniferous minerals or with leucoxene.

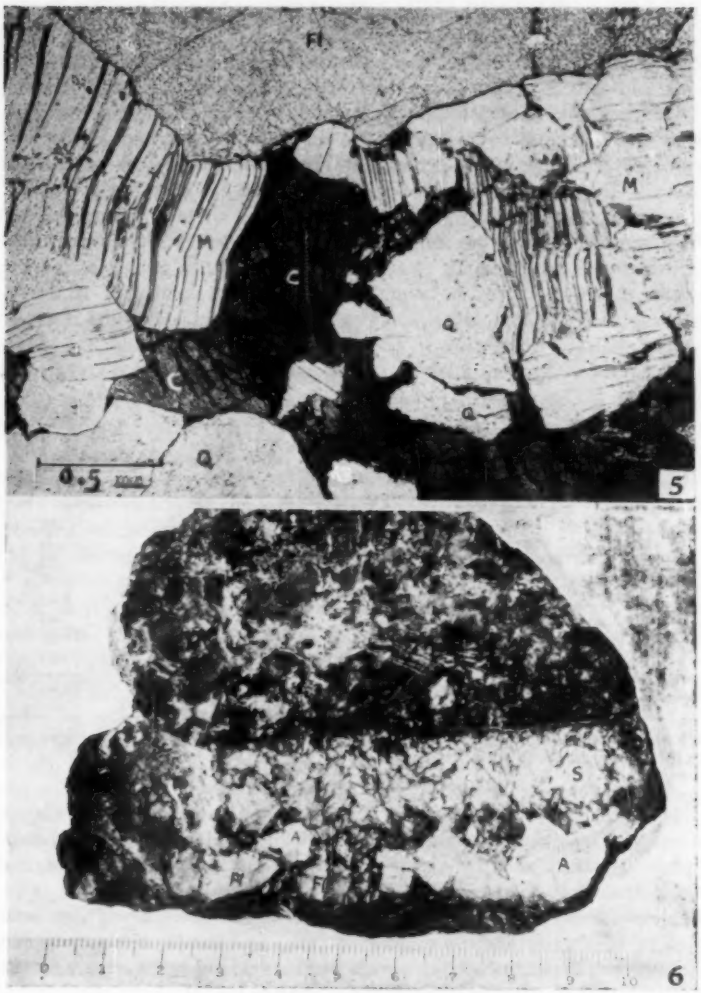

FIG. 5. Photomicrograph of greisen showing quartz (Q), muscovite (M), carbonate (C and dark gray), and fluorite (Fl). Replacement of the quartz by the carbonate is indicated by the rounded and scalloped borders. Wedges of fluorite have penetrated along the cleavage planes of the muscovite. Plain light. Magnification 37×.

FIG. 6. Polished surface showing siderite vein (S) in contact with ankerite (A), fluorite (Fl), and scheelite (Sc) in the lower half of the vein. Note sharp contact between the siderite vein and the greisen wall. Quartz vein has been removed from the lower side of the specimen. Scale in centimeters.

Cassiterite.—Cassiterite occurs commonly as short pyramidal crystals in the greisen next to the massive quartz veins, but it also forms veinlets, lenses, and irregular compact masses concentrated near the quartz veins and quartz masses. Locally it occurs in the quartz as fillings in fissures and fractures.

In thin section most of the Irish Creek cassiterite is gray, but some is colorless and some is reddish gray-brown. Zoning is noted in most of the specimens. Cleavage is distinct, and polysynthetic twinning is common.

Beryl.—Beryl occurs in the greisen (Fig. 3). The beryl crystals are slender, hexagonal prisms from 1 to 5 mm long and about 2 mm across. Some of the green beryl prisms are bent, and many are fractured. The fractures are filled with fluorite and quartz, clearly showing that beryl antedates the fluorite and some quartz, but beryl is later than the coarse-grained mica which it cuts in many places. Most of the beryl is pale green and contains microscopic inclusions, but some is yellow. The optical properties of both are the same. Table 5 shows a chemical analysis of the green variety. Some of the yellow

TABLE 5

CHEMICAL ANALYSIS OF BERYL FROM THE IRISH CREEK TIN DEPOSITS, ROCKBRIDGE COUNTY, VIRGINIA, R. E. STEVENS, ANALYST

SiO_2	63.17	K_2O	.07
Al_2O_3	18.75	Rb_2O	None
Fe_2O_3	.27	Cs_2O	.32
FeO	2.28	H_2O-	.08
BeO	12.23	H_2O	1.82
MgO	.22	TiO_2	.02
CaO	None	MnO	None
Li_2O	.07	BaO	None
Na_2O	.53		
			99.83

Note: Spectrographic tests by George Steiger, using 10-inch spectrograph, give negative results for Ag, As, B, Bi, Cd, Ge, Pb, Sb, Zn.

beryl is intimately associated with phenakite and in some places may have been replaced by phenakite, although some of the yellow beryl has altered to kaolinite. A study of thin sections indicates that beryl is contemporaneous with cassiterite.

Wolframite.—Wolframite forms veinlets in the greisen. These veinlets cut across cassiterite and muscovite patches, and small stringers penetrate biotite areas. Wolframite also forms laminae along mica cleavage planes producing an intricate meshwork, which, towards the center of the meshwork, may form almost a solid mass. Most veinlets in the biotite areas are hairlike stringers along zones of weakness or incipient fractures that feather out in the biotite areas.

Wolframite has also been reported by Ferguson (2). He states that it is associated with cassiterite in the workings of No. 2 vein, and, "Associated with the wolframite is a very small amount of scheelite which occurs in small patches and veinlets through the wolframite. The wolframite is later than the cassiterite of the same vein, for the crystals of cassiterite contain minute

veinlets of wolframite, and crystal faces of cassiterite are found adjoining the wolframite."

From the relations observed, it seems probable that wolframite belongs to the cassiterite-beryl stage of mineralization.

Tourmaline.—A little black tourmaline is present as small crystals, associated with the cassiterite. Although it occurs in fractures in the cassiterite it is believed that it was formed late in the first stage of greisen rather than during the later stages of mineralization.

Second Stage Minerals of the Greisen

Muscovite.—The muscovite of the second stage in the greisen is fine grained. As mentioned previously it seems to be optically the same as the coarse-grained first-stage muscovite. There is apparently more of the fine-grained than the coarse-grained muscovite in the greisen. Veinlets of second stage muscovite cut across the cassiterite, beryl, and quartz, but most commonly second stage muscovite forms masses and individual grains disseminated through the older minerals. Like the quartz formed during the second stage, the fine-grained muscovite may represent merely a recrystallization of the crushed first-stage muscovite during the deposition of the second-stage greisen.

Siderite.—Siderite is the most abundant carbonate. In hand specimens siderite superficially resembles cassiterite and sphalerite. It occurs in veins and in small masses both in the greisen and in the vein quartz. One vein in the East-West tunnel is 1½ inches wide and 5½ feet long (Fig. 6). Associated with it are ankerite and fluorite which form an almost parellel border on one side. A few cassiterite crystals and some small crystals of a galena-like mineral, galenobismutite, occur near the siderite vein. Much of the siderite is stained with hematite.

Ankerite.—Ankerite is abundant and occurs consistently with the siderite in the Irish Creek district. Ankerite is white, in crystalline masses, and is shown in Figure 6 with pale purple fluorite and small translucent crystals of scheelite. Ankerite along with siderite paragenetically belongs to the younger group of greisen minerals.

Parisite.—The rare mineral, parisite, a fluo-carbonate of calcium and the cerium group of rare earths, occurs sparsely at Irish Creek. Small, elongated crystals, of brownish amber color, transparent to translucent, are found associated with beryl, purple fluorite, quartz, and carbonates. Parisite resembles bastnaesite in some of its physical and optical properties. The indices of refraction for parisite, however, are much lower than those for bastnaesite.

The rare earths were identified by a spectrum analysis.

Phenakite.—Phenakite, a rare beryllium orthosilicate, known to occur most commonly in pegmatite with topaz and beryl, is found here with beryl, cassiterite, and quartz, and it is also found enclosed in and cutting chlorite and fluorite (Fig. 7). The crystals are elongated and show much the same habit as the beryl. The occurrence of phenakite in the unusual association found here has not heretofore been described.

Fluorite.—Fluorite is one of the principal constituents of the greisen. Most of the fluorite is fine grained and is white or colorless; a few of the

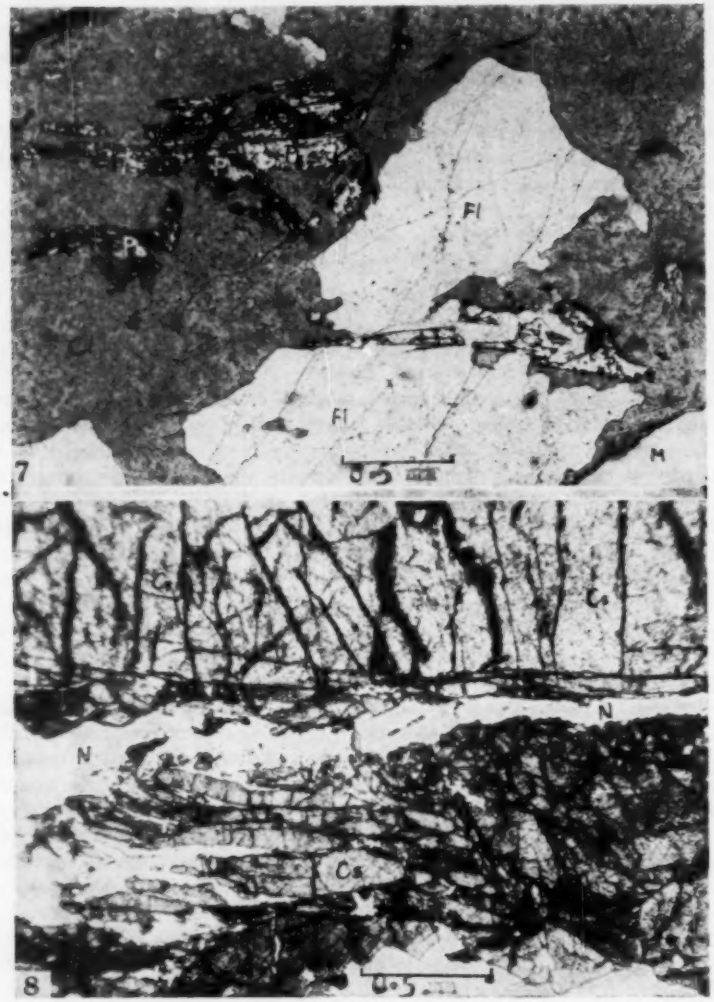

FIG. 7. Photomicrograph showing phenakite (Ph) (elongated crystals) in chlorite (Cl), and fluorite (Fl). Muscovite (M) shown in the lower right corner. Plain light. Magnification 33×.

FIG. 8. Photomicrograph showing cassiterite (Cs dark gray) being replaced by nontronite (N). Dark veinlets in fractures are hematite. Plain light. Magnification 37×.

larger individual grains are locally tinged with purple. It occurs as irregular grains intimately intergrown with the greisen minerals (Figs. 3 and 7). It penetrates fissures and fractures of the quartz veins, and in places cuts through beryl and muscovite. It is not found in the country rock.

Biotite.—A green biotite is associated with the second-stage minerals in the greisen. It is most conspicuous in the east half the East-West tunnel. It may represent alteration of the brown biotite and is in turn altered to chlorite later in the deposition of the second-stage minerals.

Chlorite.—Chlorite is common in most of the greisen. It occurs as veinlets and locally in lenses. In thin section it is pale green and slightly pleochroic, and most of it does not show abnormal interference colors. Chlorite is later than muscovite, fluorite, and biotite which it replaces. It is common along muscovite cleavages, and along boundaries of fluorite grains. Most of the chlorite is an alteration product of mica.

Scheelite.—Scheelite is intimately associated with wolframite. It is also present in the siderite-ankerite vein (Fig. 6), and crystals of scheelite as much

TABLE 6

QUANTITATIVE SPECTROGRAPHIC ANALYSIS FOR MINOR ELEMENTS IN ARSENOPYRITE FROM THE IRISH CREEK DISTRICT, ROCKBRIDGE COUNTY, VIRGINIA.
J. F. FLETCHER, ANALYST

Elements:	Cu	Ag	Ge	Sn	Pb	Bi	Zn	Co	Ni	Ti	Mg
Percentage:	0.004	0.0008	0.001	0.03	0.01	0.006	0.07	0.03	0.002	0.002	0.008

Looked for but not found: Au, Mg, Ir, Pt, Mo, W, Sb, Cd, Tl, In, Mn, Ga, Cr, V, Sc, Y, Yb, La, Zr, Th, Nb, Ta, U, Ca, Sr, Ba, P, B

as 6 mm across occur side by side with cassiterite crystals. The paragenetic relations with the associated minerals are not clear in the specimens studied, but the scheelite may represent an alteration of the earlier-formed wolframite during the second stage of greisenization.

Sphalerite.—Sphalerite is dark resinous brown, and resembles superficially the cassiterite of this locality. Sphalerite occurs as crystalline masses—the largest one observed about 2 cm across. The sphalerite is commonly found in the greisen near the quartz veins, and seems to have formed at the same time as the other sulfides.

Arsenopyrite.—Arsenopyrite is the most abundant sulfide. It is found in veins two or more inches across, in sheared vein quartz, and in the fracture zones in the greisen. Arsenopyrite occurs locally with cassiterite in the greisen. The most abundant arsenopyrite observed by the writers was that associated with quartz on the dumps of the original workings of No. 2 vein on the hill south of the old mill.

Spectrographic analysis of a random sample of arsenopyrite from No. 2 dumps is shown in Table 6.

Early assays of arsenopyrite from Irish Creek are reported to show ap-

preciable amounts of gold and silver. Hotchkiss (4 and 5) gives the following assays:

	Silver (ounces)	Gold (ounces)	Assayer
1.	38	0.1	A. S. McGreath
2.	$60		B. Silliman
3.		5.5	Ledoux and Ricketts
4.	73.73	7.36	F. A. Massie

Aikinite.—Aikinite is a sulfide of lead, copper, and bismuth ($PbCuBiS_3$). This mineral occurs as clusters of acicular crystals, blackish gray, with metallic luster. Aikinite is here associated with galenobismutite.

Galenobismutite.—A sulfide of bismuth and lead ($PbBi_2S_4$) occurs in thin, lathlike crystals, and in massive form; it is lead-gray to tin-white, with metallic luster and yellowish iridescence where exposed. This mineral was found in several specimens from the vein in the No. 1 workings. It occurs commonly in the siderite veins between the primary quartz vein and the wall rock. Thin layers of galenobismutite with aikinite were also found between laminae of muscovite. This occurrence of aikinite and galenobismutite is the first reported from Virginia.

Chalcopyrite.—Small crystals and irregular grains of chalcopyrite are present with the bismuth sulfides alongside the siderite veins. It is also found with pyrrhotite in the greisen zone.

Pyrite.—Small pyritohedral crystals, and veins of massive pyrite are found in vein quartz on the dumps of the No. 2 workings. Aggregates of pyrite grains are common in fractures in vein quartz at the No. 1 workings.

Pyrrhotite.—Pyrrhotite occurs in small masses in the greisen; most of it is intergrown with chalcopyrite and sphalerite. It is also found in the granodiorite several feet from the greisen zone, associated with grains of magnetite.

LATE VEIN MINERALS

The final stage of mineralization is represented by relatively low temperature minerals. Locally veinlets of some of these minerals cut the lodes. The minerals grouped here are believed to be primary and to have formed at relatively low temperature.

Montmorillonite.—The extreme northwest workings follow a fault or shear zone along which the granodiorite has been altered to montmorillonite. The white waxlike mass of montmorillonite is about 5 feet thick and extends beyond the limits of exploration. None of the greisen minerals was found with the montmorillonite. The thorough replacement by montmorillonite of the granodiorite in this zone suggests low temperature hydrothermal alteration, and probably marks the end phase of mineralization.

Calcite.—Calcite is a rare carbonate in the Irish Creek deposits. It was identified only in a thin veinlet that seals the small fault in the face of the East-West tunnel. The associations and relations of the calcite are described along with clinozoisite.

Clinozoisite.—Clinozoisite is a rare mineral in the Irish Creek district. It is pinkish gray and occurs in clusters of slender, flat crystals from 2 to 3 mm long. It is found in a veinlet in a shear zone in the face of the East-West tunnel. The veinlet is about a quarter of an inch wide and nearly 7 feet long, and consists of clinozoisite, chlorite—probably from the greisen—and calcite. The veinlet represents late deposition, and probably marks the end phase of mineralization in the district.

Zoisite.—A small amount of zoisite present in a calcite vein apparently was formed in this late stage of mineralization along with the clinozoisite.

Nontronite.—Nontronite is a greenish yellow, earthy to compact mineral, and has a soft, soapy feel. In thin section it was found associated with the typical greisen minerals and chiefly in fractures in cassiterite (Fig. 8), quartz, and beryl. Nontronite is also associated with fluorite, carbonates, biotite, and chlorite. Nontronite is a member of the montmorillonite group of minerals.

PRODUCTS OF SURFICIAL ALTERATION

The usual products of surficial alteration and oxidation are present near the surface. Kaolinite is present replacing the feldspars of the granodiorite; it also replaces yellow beryl, and probably replaces muscovite and some of the other silicates of the mineralized zone. Hematite results from the oxidation of pyrite, pyrrhotite, siderite, and probably some of the mafic silicates. Oxidation products of the bismuth, lead, and copper sulfides are presumably present in the oxidized zone but were not seen during this study because of their scarcity.

Scorodite.—Scorodite, a hydrous ferric arsenate, occurs with arsenopyrite, and is obviously an alteration product of the arsenopyrite. Scorodite is a soft, pale leek-green, translucent mineral. The color and strong dispersion are characteristic.

Vermiculite.—Vermiculite is a yellowish brown, micaceous mineral that resembles both biotite and nontronite. It is associated with these two minerals, and can be distinguished from them only by microscopic study. The optical properties of vericulite are different from those for biotite and nontronite, but are in close agreement with those for known vermiculites. In thin section veinlets of vermiculite are seen to cut across chlorite and other older minerals in the greisen. The vermiculite has formed a network of veinlets and local aggregates in the greisen in the northwest workings, but none has been found elsewhere in the workings of the Irish Creek district. The age relation of vermiculite suggests that it may be related to surficial alteration.

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WASHINGTON, D. C.,
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THE RELATION OF PHOSPHORITES TO GROUND WATER IN BEAUFORT COUNTY, NORTH CAROLINA[1]

PHILIP M. BROWN

ABSTRACT

Recent ground-water studies undertaken by the U. S. Geological Survey in cooperation with the North Carolina Division of Mineral Resources have delineated phosphorite deposits, tentatively regarded as being of middle Miocene age, in Beaufort County. These deposits lie unconformably on limestone of Eocene age and are unconformably overlain by late Miocene marl. The phosphorites, buried beneath strata ranging in thickness from 45 to 250 feet, underlie an area approximating 450 square miles. The total thickness of the phosphorite column throughout the area ranges from several feet to nearly 90 feet.

The phosphorite column consists of phosphatic sands and intercalated shell limestones. The sands, composed of pellets of brown sand-size collophane (probably carbonate-fluorapatite) and sand-size, flat-sided angular quartz with some silt, clay, and organic material, have a median diameter between 0.50 and 0.25 mm. Chemical analyses of representative samples of the raw sand show a variation in P_2O_5 content from 8 to 31 percent. The P_2O_5 content is apparently proportionate to the collophane content throughout the area.

Reconstruction of the geologic history suggests that the phosphorites were deposited as chemical precipitates and as *in situ* replacements in a restricted marine basin where the pH of the water acted as the primary depositional control.

Reconstruction of the hydrologic history of the phosphorites indicates that the deposits were preserved under artesian conditions; they were never subjected to alteration under water-table conditions. The absence of postdepositional alteration makes this area a potentially classic one for studies of phosphorite genesis.

Chemical analyses of artesian waters from the phosphorites and from limestones overlain by phosphorites reveal significantly greater concentrations of iodide and bromide in solution than are present in water from overlying sediments or from underlying limestones not overlain by phosphorites. Such anomalies, if present in other similar terranes, may indicate the presence of buried phosphorites.

The depth and size distribution of the material suggest a recovery method utilizing wells constructed to "pump sand."

INTRODUCTION

THIS paper presents information relative to the extent, composition, and genesis of phosphorite deposits in Beaufort County and vicinity, North Carolina (Fig. 1), in the Coastal Plain. The information presented is a by-product of recently completed geologic and hydrologic studies of the Coastal Plain by the Ground Water Branch, U. S. Geological Survey, in cooperation with the North Carolina Division of Mineral Resources.

[1] Publication authorized by the Director, U. S. Geological Survey.

Phosphorites had previously been reported in the county, and several test wells were drilled by commercial interests in 1952, presumably in an effort to locate ore-grade material that could be mined by conventional stripping methods. In connection with the recent ground-water studies, numerous well samples were critically examined for both mineral and microfaunal content, at which time notice was taken of high percentages of phosphatic material in many samples. This paper represents a compilation of data from ground-water studies and from the test wells drilled in 1952 prior to the ground-water studies.

Acknowledgments.—H. E. LeGrand and V. E. McKelvey, U. S. Geological Survey, and members of the North Carolina Division of Mineral Resources have aided materially in the preparation of this paper through their interest, criticisms, and suggestions.

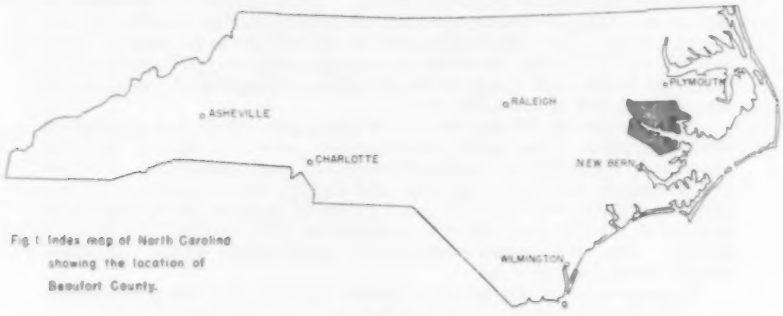

FIG. 1.

GEOLOGIC BACKGROUND

In discussing the occurrence and stratigraphic position of the phosphorites it is necessary to outline briefly the extent and lithology of post-Cretaceous sediments that occur in Beaufort County and adjoining counties. These sediments, of Paleocene, Eocene, Miocene, and post-Miocene age, compose the upper part of a monoclinal sedimentary section that strikes northeast and dips toward the southeast at rates ranging from 15 to 30 feet per mile.

Unnamed sediments of Paleocene age, described in detail in several forthcoming ground-water reports, lie unconformably on sedimentary rocks of Late Cretaceous age in Beaufort County and extend north of Beaufort County to the Virginia State line. According to present knowledge, the Paleocene sediments are confined to the subsurface in North Carolina. Their thickness ranges from 1 to more than 300 feet and they are composed of glauconitic sand, argillaceous sand, indurated shells, and impure limestone. The Paleocene sediments bear no direct relationship to the phosphorites of Beaufort County. However, their disposition and trend of thickness in the subsurface indicate basinal deposition in an area of subsidence lying north of the Neuse River.

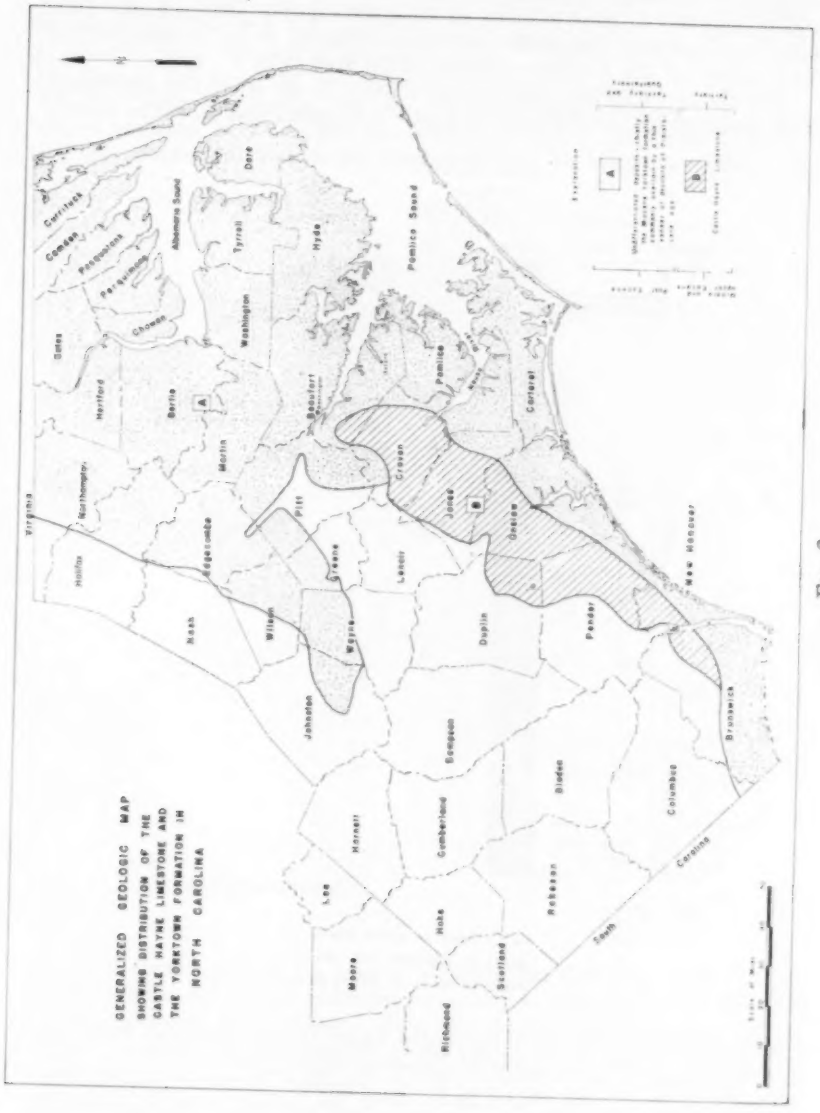
GENERALIZED GEOLOGIC MAP
SHOWING DISTRIBUTION OF THE
CASTLE HAYNE LIMESTONE AND
THE YORKTOWN FORMATION IN
NORTH CAROLINA
Currituck
Camden
Pasquotank
Perquimans
Albemarle Sound
Dare
Tyrrell
Hyde
Pamlico Sound
Chowan
Washington
Beaufort
Pamlico
Gates
Hertford
Bertie
Martin
Craven
Carteret
Northampton
Pitt
Jones
Onslow
Virginia
Halifax
Edgecombe
Greene
Lenoir
New Hanover
Wilson
Wayne
Duplin
Pender
Nash
Johnston
Sampson
Bladen
Brunswick
Columbus
Cumberland
Harnett
Lee
Robeson
Hoke
Moore
Scotland
Richmond
South Carolina
A
B

FIG. 2.

Evidence is presented suggesting that additional subsidence in this area during middle Miocene(?) time resulted in deposition of the phosphorites. This subsidence continued during the late Miocene, resulting in the observed depositional pattern of late Miocene sediments in the area (Fig. 2).

Sedimentary units that have a direct bearing on the origin and occurrence of the phosphorites are illustrated in Figure 3, a typical well section in eastern

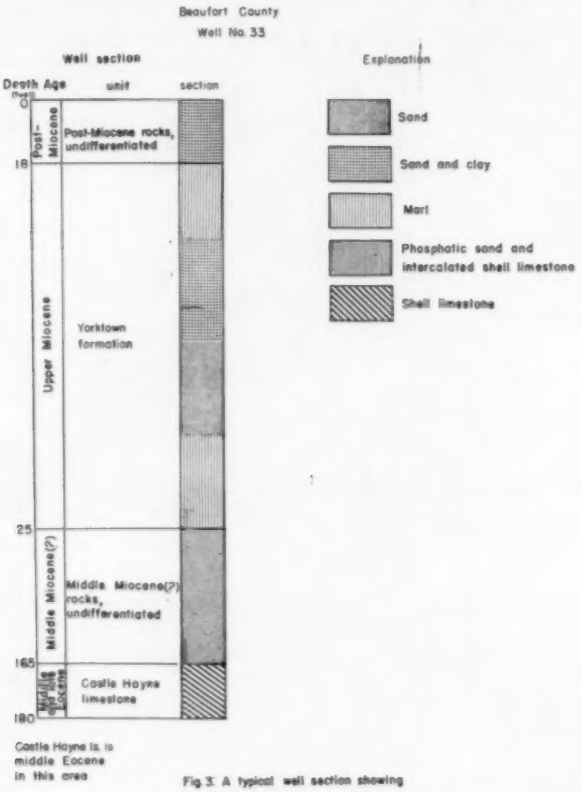

Fig. 3. A typical well section showing formational relationships in the area of phosphorite occurrence. (Well No. 33, fig. 4)

Beaufort County. The basal unit is the Castle Hayne limestone, which uncomformably overlies sediments of Paleocene age. The Castle Hayne limestone, of middle Eocene age (9, p. 6), is composed of calcitic and dolomitic shell limestone and interbedded calcareous sand and clay. The formation is exposed from near Wilmington in New Hanover County to the vicinity of the Neuse River in Craven County (6, p. 9). Northeast of the Neuse River, along

the strike, the formation is covered by a transgressive overlap of late Miocene sediments. The formation as penetrated in wells in Beaufort County is characteristically chalk white to light gray in color and is extremely hard, particularly in its upper part, where it is noticeably pyritic. The thickness ranges from less than 25 feet along the western border of Beaufort County to more than 200 feet along the eastern border. Unconformably overlying the Castle Hayne limestone in the eastern and central sections of the county (Fig. 4) are the phosphorites, which are designated here as being questionably of

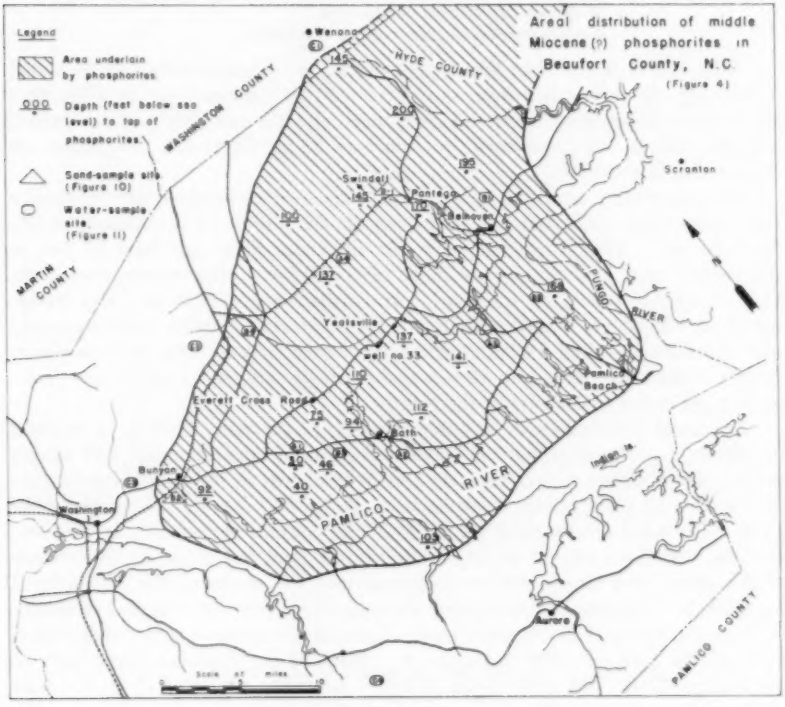

FIG. 4.

middle Miocene age. On the basis of Foraminifera that occur at the top of the phosphorite section, the indicated correlation is with the middle Miocene Calvert formation of Maryland. However, there is some question in the writer's mind as to the age assigned to the Calvert formation and the present preference is to designate the age of the Beaufort County phosphorites as middle Miocene(?). The guide foraminiferal species for this unit in Beaufort County is *Siphogenerina lamellata* Cushman, which is the only species that has been found to occur abundantly in the phosphatic sands. To date, microfossils

have been found only in the top few feet of the phosphorite section. Foraminifera from the phosphorites identified by the writer are as follows:

Siphogenerina lamellata Cushman
Siphogenerina spinosa Bagg
Cibicides concentricus (Cushman)
Discorbis cavernata Dorsey
Nonion pizzarense W. Berry
Nonion grateloupi (d'Orbigny)
Cassidulina crassa d'Orbigny
Uvigerina kernensis Barbat and von Estoroff
Bolivina calvertensis Cushman
Ellipsonodosaria calvertensis Cushman

Although it is felt that the upper part of the phosphorites can be dated tentatively, the writer is aware, as Cayeux (1) first pointed out in 1934, that phosphorite facies may transcend time lines, and the possibility is recognized that the base of the phosphorite section may be as old as late Oligocene, although this is not likely.

Unconformably overlying the phosphorites are interbedded and lenticular shell beds, marl, sand, and clay that compose the Yorktown formation, of late Miocene age. This formation ranges in thickness from less than 50 feet in the western part of the county to more than 150 feet in the northeastern part. Unconformably overlying the Yorktown formation are sand and clay designated post-Miocene, undifferentiated. This material, roughly contemporaneous with the so-called Pleistocene terrace formations as mapped elsewhere, ranges in thickness from 5 to 40 feet and generally attains its maximum thickness in the easternmost part of the county.

The areal distribution of the phosphorites, as presently known, is outlined in Figure 4. The phosphorites underlie an area of approximately 450 square miles. Overburden ranges from 45 feet in thickness in the southwestern part of the area of phosphorite occurrence to about 250 feet in the northeastern part. The total thickness of the phosphorite column in the area is variable, and the variations appear to be a reflection of both the shape of the surface of the underlying Castle Hayne limestone and the shape of the depositional basin itself. Thicknesses have been found to range from several feet to nearly 90 feet, the greatest thicknesses being found in the eastern and northeastern parts of the area outlined in Figure 4. South of the Pamlico River, east of the Pungo River, and west of the Norfolk Southern Railroad (Fig. 4), well sections indicate that the Yorktown formation rests unconformably on the Castle Hayne limestone. In a direction north and east of Pantego the lack of well samples precludes the establishment of even an arbitrary boundary, although at Wenona, Washington County (Fig. 4), the Castle Hayne limestone at a depth of 255 feet is unconformably overlain by the Yorktown formation.

THE PHOSPHORITES

Figure 5 is an idealized section of the phosphorites based on recent unpublished data collected by the Ground Water Branch, U. S. Geological Survey. The phosphorite section commonly contains phosphatic sands and inter-

calated calcitic and dolomitic shell limestones. The uppermost limestone layer is generally present, and two or more such layers are not uncommon in many sections. The intercalated limestone layers are highly competent, range from 6 inches to several feet in thickness, and generally become slightly thicker toward the base of the phosphorite section. Occasional well sections along the western and southern borders of the phosphorite area reveal coarse phosphate pebbles overlying the uppermost limestone layer. This material is obviously reworked and occurs at the base of the Yorktown formation. The phosphatic sand layers show a great variation in thickness, ranging from

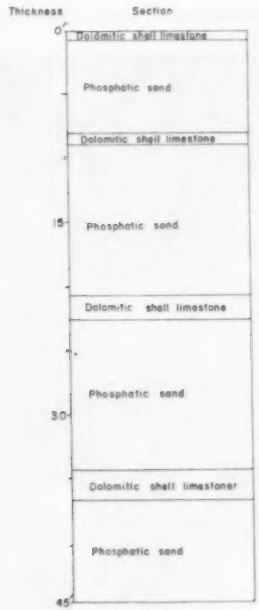

FIG. 5. Idealized phosphorite section, Beaufort County, N. C.

several feet to as much as 30 feet, and those near the base of the phosphorite section generally contain a higher percentage of collophane than those near the top.

The phosphatic sands are composed predominantly of pellets of brown sand-size collophane and sand-size, flat-sided, angular quartz grains, with lesser amounts of phosphatic silt and clay. Less common black collophane only tends to accentuate the predominant brown color of the sands. The individual grains of collophane, spherical to ovoid and irregular, commonly show banded or concentric structure. However, no nuclei have been detected even in those grains that exhibit prominent concentric laminations. Accessory min-

erals in the samples include apatite, garnet, and dolomite; the latter may represent no more than contamination of the samples by particles from the dolomitic layers intercalated with the sands.

Figure 6 is a photograph of the phosphatic sand pumped from a water well that was cased to a depth of 164 feet. The sphericity of the dark-colored collophane grains in contrast with the angularity of the light-colored quartz grains is marked and consistent throughout the area.

SIZE DISTRIBUTION OF THE PHOSPHATIC SANDS

Several analyses of size distribution was made of the phosphatic sands in connection with the determination of their hydrologic characteristics and pos-

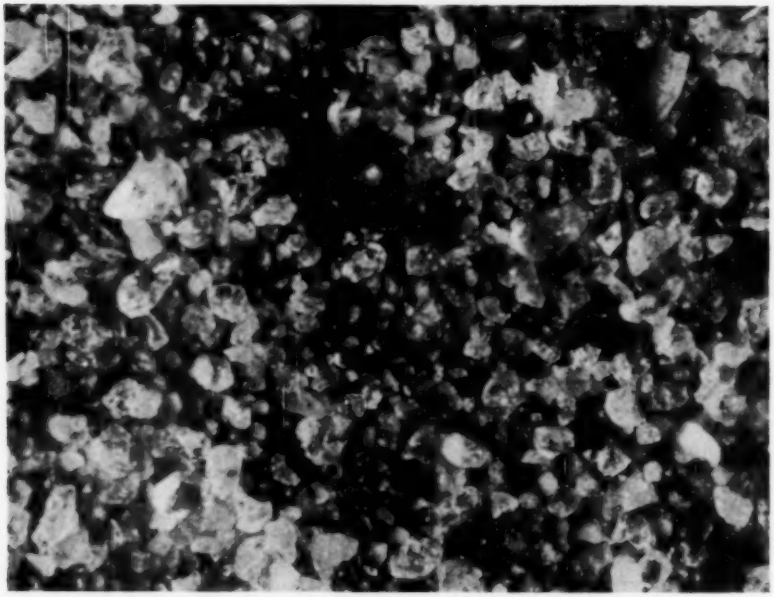

FIG. 6. Phosphatic sand pumped from a depth of 164 feet × 15.

sible value as an aquifer. Figure 7 is a histogram and cumulative frequency curve of material from a typical phosphatic sand in the area. Median diameter of the material occurs in the 1- to 2-phi size class, and essentially 70 percent of the material by weight may be classified as consisting of particles 2 phi or less in diameter. Figure 8 is a histogram and cumulative frequency curve of less typical phosphatic sand characteristic of the southern and western margins of the depositional basin. This material, characterized by a median diameter occurring in the 2- to 3-phi size class, shows a greater phi deviation and is not as well sorted as the more typical material plotted in Figure 7.

Sand and silt-clay fractions were determined for some 63 samples from 21 water wells representative of the area. In addition, the collophane-quartz ratio of the sand fraction was determined both by visual estimate and by grain count. Results of these analyses are plotted as a three-point triangular diagram in terms of sand-size collophane, sand-size quartz, and silt and clay fractions (Fig. 9). The absence of dots at the apex of the silt-clay triangle indicates that silt and clay are not dominant in the overall character of the

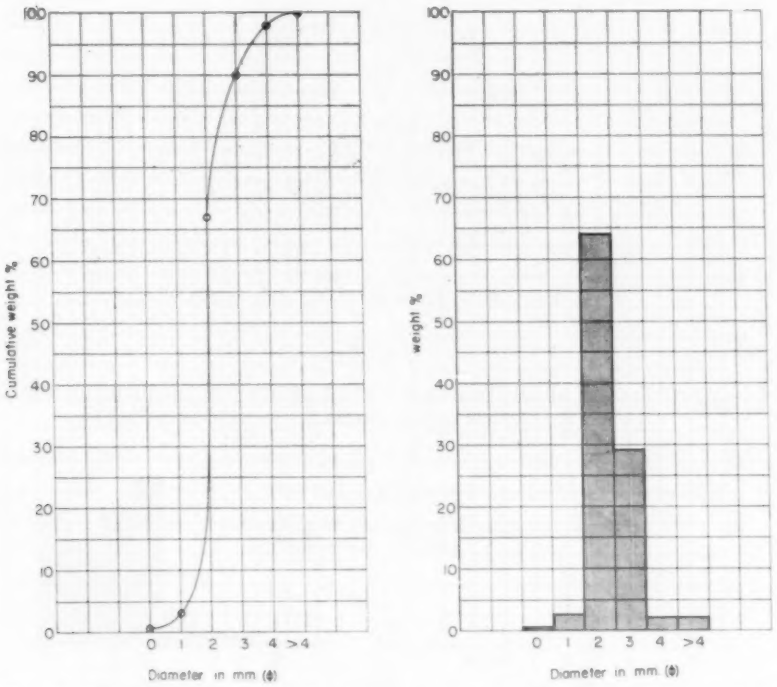

FIG. 7. Histogram and cumulative frequency curve of typical phosphatic sands in Beaufort County.

sediment. Sand-size quartz and sand-size collophane are the dominant fractions in the 63 samples analyzed, the collophane occurring slightly in excess of quartz. Sand-size collophane in individual samples ranged from about 14 to 90 percent.

CHEMICAL COMPOSITION

Few chemical analyses of the raw materials from wells have been made. Preliminary studies, based on representative samples, showed a P_2O_5 content ranging from 8 to 31 percent of the raw sand. The thickness of the sand

layer containing 31 percent P_2O_5 was 14 feet. The P_2O_5 content is apparently proportionate to the collophane content throughout the area. Combined iron and alumina content was determined for only 6 samples and was less than 2 percent in each sample. Percentages of uranium determined in two samples were 0.003 (30 ppm) and 0.008 (80 ppm), respectively. Complete chemical analyses were made of two samples. Sample B-1 (Table 1) represents a sample of typical phosphatic sand from a well at Swindell (Fig. 4). The sample was from a depth of 150 feet. Sample B-2 (Table 1) represents a

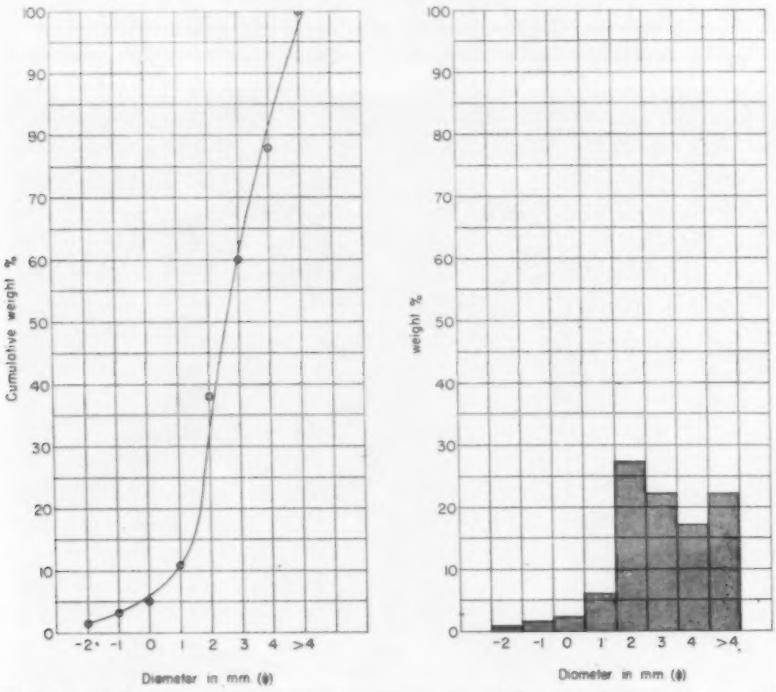

FIG. 8. Histogram and cumulative frequency curve of less typical phosphatic sands in Beaufort County.

sample of less typical material consisting of phosphatic pebbles, phosphatic clay, quartz, and shell fragments from a well near Bunyan (Fig. 4). The sample was from a depth of 45 feet.

Quantitative spectrographic analysis of samples B-1 and B-2 indicated that 13 metals occur in minor amounts in one or both samples, as follows: barium, chromium, copper, lanthanum, manganese, molybdenum, nickel, scandium, strontium, vanadium, ytterbium, yttrium, and zirconium. All analytical work on samples B-1 and B-2 was done by the Geochemistry and Petrology Branch, U. S. Geological Survey, under the direction of L. B. Riley.

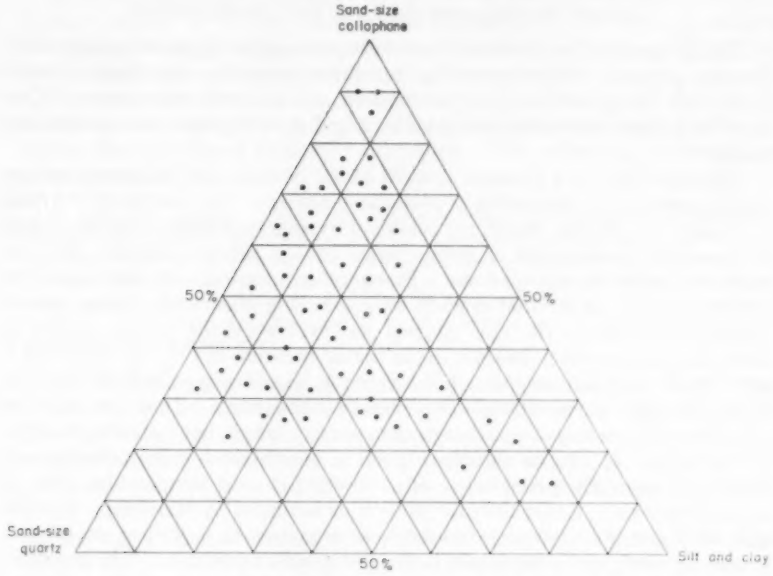

FIG. 9. Graph representing the composition of 63 well samples from the phosphate section in terms of collophane, quartz, and silt and clay.

TABLE 1

CHEMICAL COMPOSITION OF PHOSPHATE-BEARING SEDIMENTS IN BEAUFORT COUNTY

Constituents	B-1	B-2
SiO_2	51.52	11.26
Al_2O_3	.45	1.04
Fe_2O_3	.29	1.42
FeO	.20	.50
MgO	.53	.97
CaO	23.70	42.60
Na_2O	.45	.87
K_2O	.13	.22
H_2O-	.87	1.14
H_2O+	1.80	3.12
TiO_2	.06	.07
CO_2	3.39	7.88
P_2O_5	14.39	24.39
F	1.44	2.75
MnO	.00	.02
	99.22	98.25
Less 0	.61	1.16
Total	98.61	97.09

ORIGIN OF THE BEAUFORT COUNTY PHOSPHORITES

Many concepts have been advanced concerning the origin of phosphorites. Broadly grouped, these concepts fall into three categories—the classical biolith theory, the inorganic theory of precipitation, and a combination theory. Concepts of depositional environment have ranged from the open sea to restricted basins.

Kazakov (4), in a classical analysis of the geologic and chemical environments pertaining to deposition of phosphate, advanced the concept of inorganic precipitation. Briefly stated, the Kazakov hypothesis suggests that phosphate is chemically precipitated in ocean basins having shelving bottoms and unrestricted access to the open sea. Precipitation of phosphate takes place between depths of 50 and 200 m when cold upwelling waters rise during normal marine circulation. The rise of deep waters toward the surface results in increasing temperature, decrease in the partial pressure of CO_2, and increase in pH. McKelvey and associates (7) accept the Kazakov hypothesis as applying to the Phosphoria formation, with several modifications. They note that the solubility curves of apatite and carbonate overlap but do not coincide precisely, so that either apatite or carbonate may be precipitated independently; and apatite is generally precipitated at a lower pH and temperature than is calcium carbonate, rather than the reverse as indicated by Kazakov. In addition, they cite the presence of carbonaceous matter as indicating an organic source for much of the phosphate in the Phosphoria formation. The summary for the origin of the Phosphoria as presented by McKelvey and his associates (7, p. 62) is as follows:

> The Phosphoria formation accumulated in a large shelving embayment bordered by lands of low relief that contributed little detritus to the sea. Cold, phosphate-rich waters upwelled into this basin from the ocean reservoir to the south or southwest. Phosphorite was deposited from these ascending waters, probably in depths of 1,000 to 200 m, as their pH increased along with increase in temperature and decrease in partial pressure of CO_2. Carbonates were precipitated from these waters when they reached more shallow depths, at a somewhat higher pH. The phosphate-rich waters nurtured a luxuriant growth of phytoplankton, as well as higher forms of plant and animal life, some remains of which were concentrated with fine-grained materials in deeper waters away from shore. Part of the phosphate and probably some of the fine-grained silica in the formation were concentrated by these organisms. Finally, these conditions persisted over much of Permian time.

Van Vloten (10) discusses the phosphorites of the La Caja formation of Mexico and concludes that these deposits had a biochemical origin rather than a chemical origin. The following notes are adapted from his paper:

1. Upwelling cold currents are not warmed to any great extent below the zone of photosynthesis.
2. Phosphate nodules have been found much deeper than Kazakov's 200-meter limit—on the Agulhas Bank and off southern California.
3. Svendrup and others (8, p. 501) say that upwelling waters do not originate from depths exceeding 200–300 m.
4. Kazakov's (4) hypothesis does not account for coquina or immature fossils found in beds intercalated with phosphatic strata.

Both the organic and inorganic hypotheses of phosphate origin have merit, perhaps because they have many points in common. However, in terms of the reconstructed geologic environment in Beaufort County, neither theory adequately explains the origin of the phosphate deposits.

Krumbein and Garrels (5), in a paper entitled "Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials," discuss the controls of phosphate deposition. The following is quoted from their paper:

> A sediment high in calcium phosphate and low in calcium carbonate can be formed only where conditions permit the continuous removal of calcium as the phosphate, and in which the activity product of the carbonate is not exceeded. This might well occur in a restricted basin with a relatively low pH (7.0–7.5). In this environment calcium-carbonate would not be expected to form. The carbonate ion remains low and constant because of its dependence on pH and the CO_2 partial pressure in the atmosphere.

In developing the theory of origin for the Beaufort County phosphorites, the writer will borrow liberally from this concept, primarily because it allows for changes in the physico-chemical environment that account for the intercalated limestone layers found in the phosphorite section, and secondarily because this concept most readily matches the reconstructed geologic history of the area.

During Oligocene and part of Miocene time the surface of the Castle Hayne limestone was being reduced essentially to a peneplain of very low relief. Evidence for this planation is found today in the texture of the limestone as well as in isolated outliers that occur some 60 miles updip from the main outcrop and subsurface occurrence of the formation. The surface of planation, characterized by broad, shallow stream valleys and flat, featureless interstream areas, was essentially a solutional plain, as evidenced by the secondary porosity developed in the rocks due to leaching, recrystallization, and partial dolomitization, features of which processes are still preserved in the rock. Subsidence of portions of the Castle Hayne's surface probably commenced during early or middle Miocene time and continued through late Miocene time. The disposition of Paleocene sediments in North Carolina indicates active subsidence in the area north of the Neuse River, even as early as Paleocene time. The microfauna associated with the phosphorites indicates that a portion of the Castle Hayne surface was covered by a transgressive sea during middle Miocene(?) time. The disposition, thicknesses, and unconformable relationships of the Castle Hayne limestone and Yorktown formation north of the Neuse River indicate that subsidence continued in this area into late Miocene time (Fig. 2). Gardner (3, p. 11) says that faunal evidence in sediments of the Yorktown north of the Neuse River suggests their deposition in an embayment protected from the influence of warm oceanic waters lying east of the embayment.

Subsidence of the Castle Hayne surface caused marginal flooding by epicontinental seas and resulted in the formation of banks, bars, and barriers. In just such manner are barred basins formed, and submergence of a limestone terrane generally would be expected to result in a higher incidence of barriers

than would more erodible material, because of the uneven nature of the depressed surface, as well as its relative resistance to erosion.

The basin of deposition for the phosphorites appears to have been a low solutional area, or uvala-type structure, in the limestone that was essentially severed from the sea to the east, south, and west. In these areas of the basin are found the highest phosphate-to-carbonate ratios in the phosphorite column, suggesting the greatest contrast between the normal marine and restricted basin environments. The basin probably had limited access to the open ocean toward its northeast extremity (northeast of Pantego, Fig. 4); in this direction the phosphate-to-carbonate ratio is lowest. Additional test drilling in this northeast direction should intersect equivalent and gradational facies having a still lower phosphate-to-carbonate ratio. Such gradational facies will possibly consist of sandy phosphatic limestones or sparsely phosphatic calcareous sands.

The basin probably supported a rich marine life, consisting of planktonic and nektonic forms, in its phosphate-rich waters. Phosphatized fish teeth and vertebrae occur commonly in the deposits, as evidence of organic detritus, in intimate association with the more spherical collophane. This suggests that precipitation and replacement occurred simultaneously while little else other than quartz was being deposited in the basin. In such an environment the less resistant organic constituents would have a tendency to pass into solution and be precipitated in the form of the spherical collophane so common in the deposits, whereas the more resistant organic constituents would tend to be replaced.

Benthonic forms have not been recognized in the phosphatic sand layers, with the exception of the uppermost layer, although such forms are present in the intercalated limestones. No glauconite has been recognized in the phosphorite section. Dietz and associates (2, p. 832) state that areas where glauconitic sands occur are "among the most oxidizing environments of the sea floor." The absence of glauconite in the phosphorite section is attributed to slightly reducing bottom or near-bottom conditions in the depositional environment.

Occasionally the barrier between ocean and basin was breached, allowing entrance into the basin of benthonic forms and the establishment of more normal circulation between the marine and basin environments. The resulting entrance of benthonic forms and the rise in pH value of waters in the basin would account for the intercalated shell-limestones observed in the phosphorite section. Such a barrier need not have projected above water level. Ideally, the barrier should have been elevated sufficiently so as to impede circulation between ocean and basin, but not to such an extent as to impede the normal flow of planktonic and nektonic forms into the basin. Such circulation, possibly aided at times by onshore winds, would periodically or continually replenish the supply of phosphate entering the basin. If the barrier were composed of fragmental material, its alternate destruction and construction would more readily explain the cyclic depositional pattern observed in the phosphorite section.

SOURCE OF THE PHOSPHATE

The source of the phosphate is believed to have been the phosphate-rich organic life present in the basin, and this source may have been supplemented by phosphate in solution derived from the sparsely phosphatic Castle Hayne limestone exposed to the west and southwest of the basin during early and middle Miocene time. If the basin waters are assumed to have been essentially saturated with phosphate, then an amount equivalent to the increment entering the basin (from the open ocean to the northeast and from the exposed land to the west) should have been deposited yearly. The banded and concentric structure observed in individual grains of collophane indicates changes, perhaps seasonal, in the physico-chemical environment of deposition.

There is little doubt that the spherical collophane and the angular quartz were deposited in the basin contemporaneously because they are consistently a mixture. Little is known concerning the quartz other than its observed angularity. It is the writer's opinion that the source of the quartz was lag deposits from the Castle Hayne limestone surface. Such insoluble residues or lag deposits may have entered the basin as windblown material or water borne material from the perimeters of the basin. Additional studies of insoluble residues from the Castle Hayne limestone and of the inclusions in quartz grains present in the phosphorites may offer definite clues to the province of origin of the quartz grains associated with the collophane.

GROUND-WATER RELATIONSHIPS

In determining the hydrologic relationships of the various potential aquifers in Beaufort County, an effort was made to separate the waters from the Yorktown formation, the middle Miocene(?) phosphorites, and the Castle Hayne limestone, on the basis of their chemical constituents. Such a means of separation is valuable in determining subsurface formational boundaries in the absence of well cuttings. In certain areas, where recharge occurs by upward or downward leakage across formational lines, the constituents commonly determined in standard water analyses are not effective in determining formational boundaries. Such proved to be the case with regard to the aquifers in Beaufort County. The chemical characteristics of the ground water seemed to reflect depth below land surface more readily than individual formational characteristics, and no clear differentiation could be established for waters emanating from the buried phosphatic sands. Because the source of the phosphate was believed to have been primary organic material, it was felt that the waters from the phosphatic sands might contain significant concentrations of boron, bromide, iodide, and fluoride, in contrast to both overlying and underlying rocks.

Unfortunately, the stability of these constituents in the artesian hydrologic environment is little understood. Bromide and iodide occur in negligible quantities in fresh waters outside the phosphorite environment in North Carolina. Boron and fluoride seem to show no predictable environmental preference that is not directly or indirectly related to depth below land surface. Table 2 suggests that bromide and to a lesser extent iodide may be of value

in determining the presence of buried phosphorites and of limestones overlain by phosphorites. The fact that limestones overlain by phosphorites contain waters having greater than normal concentrations of bromide and iodide further suggests that the limestones, with no direct access to the surface, are being recharged by water leaking downward through overlying phosphatic material. It is pertinent to note that the artesian waters from the phosphorites and underlying limestones contained no reported PO_4 in any of the analyses submitted to date.

It is felt that additional study of the chemical constituents of natural ground waters emanating from phosphorites may establish a useful tool that can be utilized in the search for buried phosphorites in similar terranes.

TABLE 2

CHEMICAL ANALYSES OF SELECTED GROUND WATERS FROM THE NORTH CAROLINA COASTAL PLAIN

Sample sites	Constituents (ppm)			
	Br	B	I	F
A-1	0.4	0.1	0.1	0.3
A-2	.5	2.1	2.1	.6
A-3	.4	.4	.3	.8
A-4	.8	.1	.0	.6
B-1	.6	.5	.0	.4
B-2	.8	.4	.3	.4
B-3	.5	.2	.1	.2
B-4	6.4	.5	.0	.6
C-1	.0	.0	.0	.0
C-2	.0	.4	.0	.5
C-3	.0	.3	.0	.2
C-4	.0	.7	.0	.4
C-5	.0	.2	.0	.3

Analyses (ppm) showing bromide (Br,) boron (B), iodide (I), and fluoride (F) content of waters emanating from the following: A. Phosphatic sand, B. Limestone overlain by phosphatic sand, C. Limestone not overlain by phosphatic sand.

Analyses by Russell McAvoy, Quality of Water Branch, U. S. Geological Survey, Raleigh, N. C.

Ideally, a survey of the chemical constituents of water from existing wells in areas surrounding known phosphorite occurrences, such as Hyde and Pamlico Counties in North Carolina, would provide an inexpensive method for the delineation of additional phosphorite occurrence.

SUMMARY

Briefly, it should be stated that the preservation of the phosphorites of Beaufort County under artesian conditions apparently has left undisturbed many genetic features that may be of value in the interpretation and determination of the favorable environment for deposition of phosphate, and a careful geologic and hydrologic study of this area could lead to other worthwhile

discoveries in the Coastal Plain. The possible role of ground water in economic exploitation of these deposits is largely undetermined but worth exploring. Ground water in this material is under artesian head and will generally rise to within a few feet of the land surface in all sections of the basin. Whether the water can be utilized as a driving force in the recovery of the phosphate by means of specially constructed wells designed to "pump sand" will have to await additional experimentation.

In conclusion, the writer would like to emphasize the following points:

1. The P_2O_5 content of the phosphatic sands has been found to range from 8 to 31 percent.
2. The often-recognized association of phosphorites and underlying limestones is not merely fortuitous; there is a primary genetic association in many cases.
3. Inorganic and organic equilibrium necessary for the precipitation of collophane is most readily established in a closed or limited-access basin.
4. The presence of bromide and iodide in natural ground waters suggests a geologic tool that may be useful in prospecting for buried phosphorites.
5. A genetic study of the Beaufort County phosphorites may aid in predicting the location and extent of similar deposits.

GROUND WATER BRANCH,
U. S. GEOLOGICAL SURVEY,
RALEIGH, N. C.,
Aug. 21, 1957

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REFLECTANCE OF OXIDIZED COALS

D. CHANDRA

ABSTRACT

To determine the effect of weathering on their optical properties, coals have been oxidized by two different methods under controlled conditions. No significant change in reflectance or in petrological composition has been found. The results should prove useful from the point of view of economic geology because from the study of reflectance of a sample from an outcrop it should be possible to predict some of the properties of the remainder of the seam lying beneath.

INTRODUCTION

In 1948 Seyler (1) stated that the petrology of a coal does not alter materially when it is subjected to weathering, even if this weathering is profound. However, as Seyler did not publish any evidence in support of these suggestions, and particularly nothing relating to reflectance under these conditions, the author artificially oxidized certain coals with the object of determining the nature of any change in quantitative terms.

EXPERIMENTAL PROCEDURE

Preparation of Specimens.—Two coals were used in this investigation and each was oxidized differently. The Thorne Hazel coal (Thorne Colliery, High Hazel Seam) was ground to −25 +150 B.S.S. and air at 150° C was passed over it for periods of 18, 42, 66 and 90 hours, after each of which periods a sample was set aside for reflectivity analysis. The other coal—Ellington High Main (Ellington Colliery, High Main Seam) was ground to −72 B.S.S. and oxygen at 110° C was passed through it, samples for reflectance measurements being collected after 200 and 418 days.

Each sample was mixed with molten carnauba wax colored with oil-soluble olesol black, and cast in a small pill box. When hard the lower surface of the pill box was peeled off and the carnauba wax briquette was polished successively on moistened Selvyt cloths with different grades of powdered alumina—"alumina I," "alumina II," and "gamma alumina"—products of Messrs. Griffin & Tatlock Ltd., London. For each grade of alumina powder a separate piece of Selvyt cloth was used and the briquettes were thoroughly washed between each stage of polishing to avoid contamination of any one grade of alumina powder by powder of another grade. After polishing, the briquettes were again washed with distilled water. Subsequently the briquettes were dried in a stream of air.

Reflectance Measurements.—For the purpose of reflectance measurements the technique described by Seyler et al. (2) was more or less followed. The reflectance of vitrinite on each sample was measured in polarized light using a

TABLE 1

RESULTS OF REFLECTIVITY IN OIL OF OXIDIZED COALS IN PERCENT OF INCIDENT LIGHT

Sample	*Reflectance in oil in percent of incident light	Average
Thorne Hazel		
Raw	0.77, 0.79, 0.72, 0.67, 0.74, 0.83, 0.67, 0.76, 0.75, 0.76	0.75
18 hrs.	0.74, 0.79, 0.76, 0.76, 0.82, 0.82, 0.74, 0.75, 0.75, 0.85	0.78
42 hrs.	0.73, 0.81, 0.75, 0.75, 0.81, 9.81, 0.71, 0.75, 0.74, 0.68	0.75
66 hrs.	0.87, 0.88, 0.87, 0.85, 0.83, 0.88, 0.85, 0.85, 0.83, 0.90	0.86
90 hrs.	0.75, 0.85, 0.86, 0.89, 0.62, 0.86, 0.86, 0.70, 0.80, 0.83	0.80
Ellington High Main		
Raw	0.77, 0.63, 0.87, 0.67, 0.83, 0.62, 0.79, 0.85, 0.69, 0.77	0.75
200 days	0.85, 0.69, 0.89, 0.80, 0.79, 0.80, 0.84, 0.78, 0.72, 0.76	0.79
418 days	0.68, 0.82, 0.73, 0.73, 0.79, 0.64, 0.70, 0.74, 0.70, 0.74	0.73

* Each value in this column represents an average of ten measurements made at one spot.

TABLE 2

COMPARISON OF RESULTS OBTAINED ON PREPARATIONS IN CARNAUBA WAX BY BEREK-PHOTOMETER WITH THOSE DERIVED FROM A BLOCK PHOTOCELL

Coal	Obtained on ground coal in carnauba wax preparation, by Berek-Photometer R_o	Obtained on block of coal by photocell R_o
Thorne Hazel	0.76	0.83
Ellington High Main	0.75	0.85

R_o = Reflectance in oil in percent of incident light.

TABLE 3

CHEMICAL COMPOSITION OF OXIDIZED COALS

Sample	Air dried			Parr's				
	Moist. %	Ash %	S %	V.M. %	C %	H %	O %	N %
Thorne Hazel								
Raw	6.6	1.9	1.0	37.7	83.4	5.4	9.6	1.6
18 hrs.	3.5	1.7	1.0		81.7	5.1	11.5	1.7
42 hrs.	3.6	1.6	0.9		81.3	5.0	12.0	1.7
66 hrs.	3.3	1.5	0.9		80.1	4.9	13.3	1.7
90 hrs.	3.5	1.4	0.9		80.7	4.9	12.9	1.5
Ellington High Main								
Raw	9.6	0.9	0.9	37.4	81.8	5.3	11.1	1.8
341 hrs.	1.5	1.5	1.0		78.4	4.9	14.9	1.8
42 days	0.9	1.1	1.0		75.9	4.5	17.8	1.8
84 days	0.8	1.2	1.0		73.0	4.1	21.0	1.9
200 days	1.7	1.3	1.0		73.0	3.9	21.4	1.7
418 days	2.8	1.0	1.0		70.7	3.7	23.8	1.8

Thorne Hazel—Oxidized at temperature 150° C.
Ellington High Main—Oxidized at temperature 107° C.

Leitz green filter (maximum intensity at a wave length of 5,300 Å) on a Berek-Photometer with a Leitz fluorite oil immersion objective (coated, magnification ×60), using a cedar oil of refractive index 1.519 for $\lambda = 5300$ Å. During the measurement the polarizer was kept at the 45° azimuth. At each of ten spots on the briquette ten measurements at the position of maximum reflectivity were made. All measurements were taken on vitrinite.

ACCURACY OF THE MEASUREMENTS

Table 1 gives the average value obtained at each spot together with the mean of these for each material. It will be seen that there is little variation in the individual measurements. The variations could be attributed to one or all of the following causes:

(I) Variation in the polish on the surface of the sample;
(II) Variation within the vitrinite of the sample;
(III) Variation in the alignment and focussing of the measuring equipment;
(IV) Errors in matching and reading the scale when either the zinc blend (standard) or the specimen was in position.

However, by taking an appropriate number of measurements, these variations could be reduced to a minimum.

In order to gain some idea of the order of accuracy involved, reflectances of raw coals obtained by this method have been compared with those obtained by a photocell under standard conditions of measurement (i.e., measurements were made on block samples having a known orientation and free from carnauba wax smearing). The results are shown in Table 2. It will be seen that the difference between results obtained by the two methods is small. The reflectances determined by the present method appear to be lower than those obtained by means of a photocell. This is probably due to carnauba wax smearing. Similar results have also been obtained by McCartney (3). Hence it is concluded that by comparing a large number of results by the two methods it would be possible to find a correction factor whereby the absolute accuracy of the technique of measurements mentioned in this paper could be improved. However, whatever the accuracy of the present method, the results obtainable by this technique are reproducible and comparable, thereby fulfilling the necessary immediate requirements.

DISCUSSION OF RESULTS

In Table 3 are chemical analyses of the samples that will give an indication of the nature of the chemical change involved during oxidation. In the accompanying Seyler coal chart, Figure 1, the chemical analyses of the oxidized Thorne Hazel and Ellington High Main coals are plotted. It will be found changes involved during oxidation, the reflectance remains almost the same as shown in Table 1 and Figure 2. Also within the usual limits of accuracy no difference is found in the petrological composition, as shown in

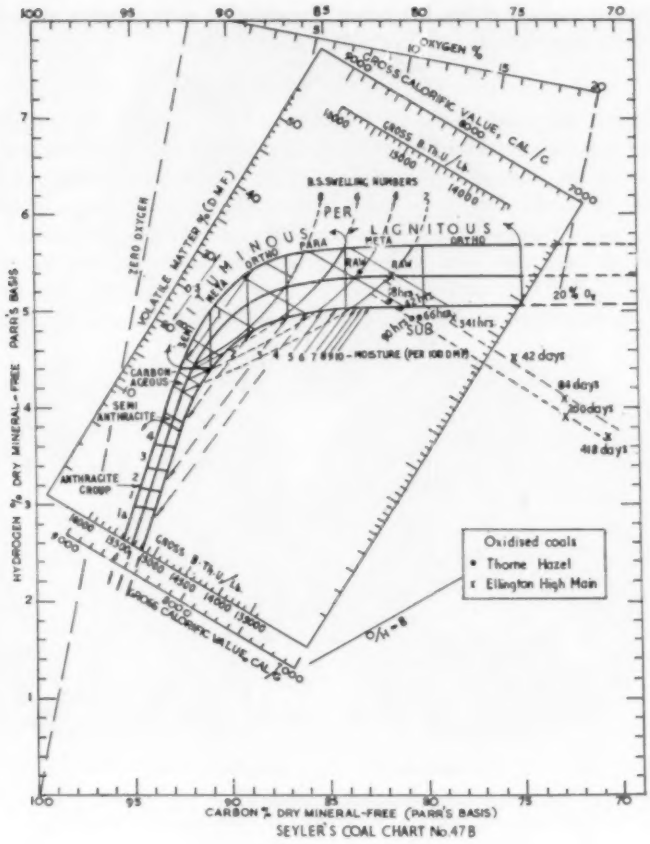

FIG. 1. CHEMICAL COMPOSITION OF OXIDISED COALS

Figure 3. This will also be evident from the photomicrographs of Ellington High Main at various stages of oxidation, as shown in Figure 4.

During this investigation the author found no oxidation rims (4).[2] In another experiment a carbonized briquette[3] of Thorne Hazel was exposed for 20 minutes in a current of air at 300° C. Oxidation rims were found near the air-inlet end but not on the end of the briquette remote from this, although the oxygen content of the coal in this region had increased. Thus it is evident

[2] Oxidation rims are supposed to be brighter rings surrounding particles of coal after oxidation as seen under the microscope.

[3] The briquette was prepared from ground coal (−240 B.S.S.) pressed at 10 tons/sq. in. at room temperature without a binder and was about 10 cm × 1 cm × 1 cm in size. Rate of heating was 1¼° C/minute.

that the mechanism of the formation of oxidation rims remains unknown, as stated by Schroeder (4).

CONCLUSIONS

Separate relationships (5, 6, 7) have been found between the reflectance of vitrinite and the chemical properties of uncarbonized and of carbonized coals; whereas in the case of oxidized coals no such correlation exists as the reflectance of oxidized coals remains unchanged with the change in chemical composition. However, from the relationships between reflectance of uncarbonised coals and their chemical properties, as established by previous workers (5, 6, 7), it would be possible to predict the original properties of a coal from the reflectance of an oxidized sample of this coal and, as pointed out

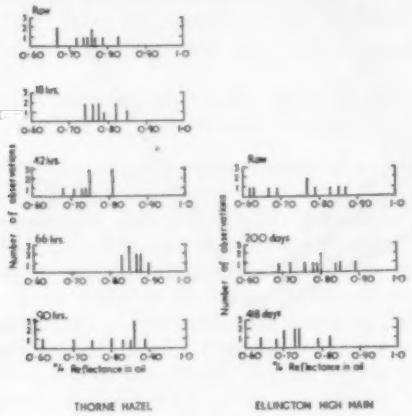

FIG.2. VARIATION OF REFLECTANCE AT DIFFERENT SPOTS IN OXIDISED COALS

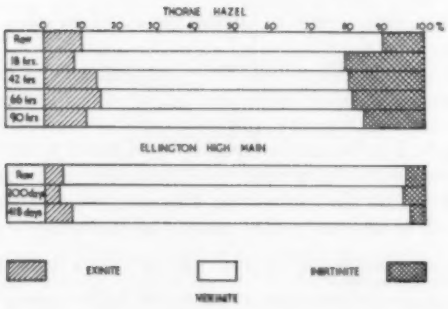

FIG.3. PETROLOGICAL COMPOSITION OF OXIDISED COALS

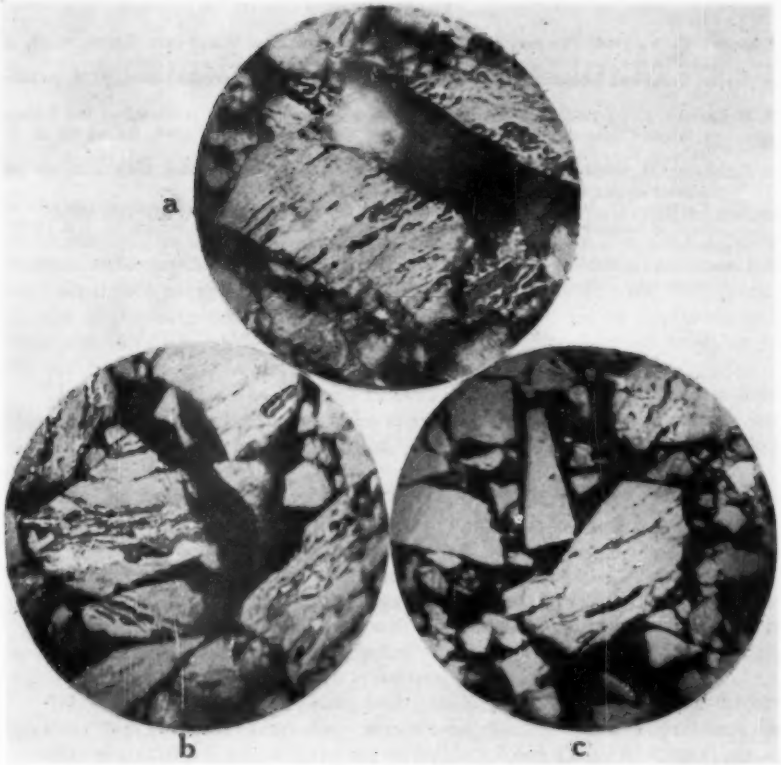

FIG. 4. Photomicrographs of Ellington High Main coal at various stages of oxidation. A, raw coal; B, 200 days; C, 418 days. ×325.

by Seyler (1), this would prove helpful when prospecting in new coalfields where the only coal available is in outcrops. Further, for the purpose of petrological analysis, it is not necessary to store samples in inert atmospheres.

ACKNOWLEDGMENTS

The author wishes to thank both Dr. C. A. Seyler and Dr. I. G. C. Dryden for their help during the course of the work. Also the permission of the British Coal Utilization Research Association to publish this work is gratefully acknowledged.

THE BRITISH COAL UTILISATION RESEARCH ASSOCIATION,
LEATHERHEAD, SURREY,
July 18, 1957

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SCIENTIFIC COMMUNICATIONS

STUDY OF MANGANESE ORE MINERALS OF INDIA

India has been an exporter of manganese since 1892 and still continues to be one of the leading producers of the world. Since Fermor's (1909) memoir on manganese deposits, very little work on Indian manganese has been attempted using modern laboratory techniques. As a result, the nomenclature of the individual mineral species is, at present, highly confusing and unsystematic. Knowledge of the textural and physical-chemical relations of the ore minerals is in a similar state.

The present work was initiated to stimulate laboratory study and to help clear up the existing confusion. An attempt has been made to compare the ore minerals of Sweden, South Africa, Cuba, Mexico, and the United States with those of India.

Previous workers employed an isolated line of attack such as chemical, ore microscopy, differential thermal analysis, or, more recently, x-ray diffraction. The present work involves the correlation and coordination of data obtained from numerous techniques including ore microscopy, x-ray diffraction, differential thermal analysis, electron microscopy, and emission spectrography. Synthetically prepared oxides and well crystallized, natural manganese ore minerals were used as standards against which poorly-crystallized, intimately mixed natural ore minerals were compared.

Some encouraging results have been obtained. Detailed study of the ore textures has revealed interesting paragenetic relations and information on possible modes of formation of the ore minerals. Comparison of natural oxides with the synthetic oxides has provided data on physical-chemical relations that should aid in understanding the conditions of formation of natural manganese ore minerals.

More work along these lines, using carefully collected samples with emphasis on geologic control, is in progress now.

This study was suggested and stimulated by Professor Alan M. Bateman. Valuable help was given by Professors Mead LeRoy Jensen, Horace Winchell, and Karl K. Turekian of Yale University. Samples were provided by the writer and by Dr. Michael Fleischer of the U. S. Geological Survey, Dr. George Switzer of the Smithsonian Institution, and Professor Clifford Frondel of Harvard University. The synthetic oxides were obtained from the Winchester Research Laboratories in New Haven. Samples were also sent by the Mysore Geological Survey of India.

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November 13, 1957

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DISCUSSIONS

THE APATITELIKE MINERAL OF SEDIMENTS

Sir: Although one cannot safely prognosticate the composition of any particular mineral component from a general knowledge of environmental conditions, nevertheless, carelessness seems to have arisen with respect to use of the term, "apatite," in the description of what is commonly the principal component of certain *phosphorites*. Recently "fluor-apatite" has been casually mentioned by C. H. Lund (Econ. Geol., 52, p. 582–583) as the chief component of certain phosphatic sediments in Florida (1).

Were the mineral involved actually fluorapatite, i.e. containing less than one percent of both carbon dioxide and water as well as more than three percent of fluorine, its occurrence under these circumstances would be most unusual. One readily suspects, however, that the principal mineral is actually *francolite*, inasmuch as this is the common fluorine-bearing component of such deposits (2).

Francolite, a carbonate apatite, has been well defined through reexamination (3, 4), but the name first appeared more than a century ago (5). It has previously been suggested (6) that *collophane* is an appropriate "wastebasket" term (comparable to *limonite*) for the mineral component of such rocks as *phosphorites* (6, 7). "Fluorapatite" should not be used in a vague general sense.

If the fluorine content is less than one percent, *dahllite*—often erroneously spelled "dahlite"—is appropriate for the carbonate hydroxyapatite of phosphatic sediments (8). Collophane can be used for cryptocrystalline substances for which the composition is not definitely established. However, a truly amorphous substance with a composition approximating that of apatite has not been discovered (6); even such fossil materials as conodonts demonstrate an apatitelike structure when examined by X-ray diffraction methods (9).

In view of the extensive recent literature on rock phosphates, in general, and Hutchinson's treatment (10) of deposits formed from guano, in particular, no useful purpose is served by presentation of casual descriptions that disregard existing concepts and nomenclature.

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OHIO STATE UNIVERSITY,
COLUMBUS, OHIO,
October 3, 1957

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REVIEWS

Guidebook of Western San Juan Mountains, Colorado. By NEW MEXICO GEOLOGICAL SOCIETY. Pp. 258; figs. 105. New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico, 1957. Price $7.25.

This book is about equally divided between mining geology and sedimentary stratigraphy. Eight of the 15 technical articles are devoted to "hard rock" geology. They were written by Vincent C. Kelley of the University of New Mexico, Waldemere Bejnar, consulting geologist, James R. Hillebrand of the Idarado Mining Co., Abraham Rosenzweig of the University of New Mexico, Philip T. Hayes and Charles B. Read of the U. S. Geological Survey, and William L. Chenoweth of the Atomic Energy Commission. The stratigraphic studies are by Donald L. Baars and Ray L. Knight of Shell Oil Co., Sherman A. Wengerd of the University of New Mexico, and Frank E. Kottlowski of the New Mexico Bureau of Mines and Geology. General geology was covered by Kottlowski and Kelley. Geomorphology and glaciology were the field of Kirtley F. Mather, Professor Emeritus of Geology at Harvard University.

There are road logs from Albuquerque to Durango, Durango to Silverton, Silverton to Ouray, Silverton to Eureka, Silverton to Durango by railroad, Durango to Cortez, and Durango to Pagosa Springs.

The articles on mining geology include "General Geology and Tectonics of the Western San Juan Mountains," "Lithologic Control of Ore Bodies," "Vein and Fault Systems," "The Idarado Mind," "Mines and Ore Deposits from Red Mountain Pass to Ouray," "Mineralogical Notes on the Silverton Quadrangle," "Geology of Ouray," "Coal Resources of the Durango Area," "Radioactive Titaniferous Heavy-Mineral Deposits of San Juan Basin," "Mines and Ore Deposits Near Ouray." A couple of articles are of a historical nature, this being a very historic region.

The volume concludes with abstracts of all the papers presented at meetings of the New Mexico Geological Society from 1954 to 1957.

A colored geologic map of the area covered by the field conference is in a pocket on the back cover.

MARTIN VAN COUVERING

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Nov. 15, 1957

The Proterozoic in Canada. Edited by JAMES E. GILL. Pp. 191. Royal Society of Canada, Special Publications, No. 2, University of Toronto Press, Toronto, 1957. Price, $5.95.

This is the second volume of this type being published by the Royal Society, the first being THE GRENVILLE PROBLEM. The Proterozoic is made up of 25 articles by 24 different authors, a single author being responsible for more than one article. The first four of these articles deal with the Proterozoic in Canada, discussion of it, Life in the Proterozoic, and Dating of the Proterozoic of Canada.

The main body of the volume comes under the heading of "The Canadian Shield." Under this are considered the Proterozoic of various areas, mainly in Quebec and Ontario, but also in Manitoba, Northwest Territories, Canadian Arctic and Labrador. This group of papers is followed by three articles on the Proterozoic of Eastern Canada—Appalachia, British Columbia and Alberta, and the Yukon. The volume is concluded by a chapter entitled Summary and Discussion, by the editor, Dr. Gill. The contributors are drawn mostly from the Geological Survey of Canada, the Provincial Departments of Mines, and the Universities of McGill, Toronto, and British Columbia.

The Proterozoic rocks have created much interest because they contain important mineral deposits, which have led to their examination in great detail. They contain the iron deposits of the Lake Superior region, the copper deposits of Michigan, the Sudbury nickel-copper-platinum deposits, the silver deposits of Cobalt and the uranium deposits of the Shield Area. In the west are also the great zinc-lead-silver deposit of the Sullivan mine. This gives added interest to the present volume.

The various articles give what appears to be a complete coverage of what is known about the Proterozoic in Canada and should prove to be a very valuable reference book. The Royal Society and the Editor are to be congratulated on a job well done.

The Admirable Discourses of Bernard Palissy. Translated by AURÈLE LA ROCQUE. Pp. 264. University of Illinois Press, Urbana, Illinois, 1957. Price, $5.50.

The author, who is Professor of Geology at Ohio State University, feels that in the history of geology the writings of Palissy are less well known to geologists than they should be. Palissy, who was born around 1510 and died in 1590, was a rather remarkable man who disputed many of the tenets of his contemporaries and peers and questioned some of the teachings of the established church. His discourses deal with groundwater, artesian wells, sedimentation, stratification, the origin of fossils and crystals. He is perhaps best known for his discussion of marl and his discourses on ceramics. He was an original observer.

His many discussions deal with waters, tidal bores, metals and alchemy, ice, various kinds of salts, rocks, clays, and fossils. They are in the form of question and answer, or "theory" and "practice." Palissy recognized that springs were fed by rain water, that fossils were the remains of animals and plants and those found far from the sea are identical with marine forms. He grew crystals and recognized the constancy of crystal angles. He realized that rocks were formed one layer at a time above each other, and accumulated in horizontal layers.

For those interested in the history of geology this is an interesting book to read. It gives one further insight into the evolution of some of our earlier geologic ideas.

S. James Shand, Memorial Volume. Edited by M. S. TALJAARD, *et al.* Annals of the University of Stellenbosch, Vol. 33, Sec. A, Nos. 1–11. Pp. 569. Stellenbosch, 1957. Price £5–5–0.

The University of Stellenbosch is to be congratulated in bringing out this large tome in memory of Professor Shand, who was head of the Department of Geology and Mineralogy there from 1911 to 1937. It is a fitting tribute to one who has made such important contributions to petrology.

The volume takes the form of 11 articles by as many authors, as follows: Critical Review of Superimposed and Antecedent Rivers in Southern Africa, by S. Maske; Diorites of Yzerfontein, Darling, Cape Province, by S. Maske; Tectonic History and Sedimentational Aspects of the Witwatersrand and Ventersdorp Systems in the Far East Rand, During Upper-Witwatersrand Time, by A. F. Cluver; Morphological Reconstruction of the Kimberley-Elsburg Series, with Special Reference to the Kimberley Group of Sediments in the East Rand Basin, by F. S. J. de Jager; River Evolution and the Remnants of the Tertiary Surfaces in the Western Little Karoo, by C. J. Lens; Mineralogy and Genesis of the Lead-Zinc-Vanadium Deposit of Abenab West in the Otavi Mountains, South West Africa, by W. J. Verwoerd; Application of the "Stereographic Projection" to Problems in Structural Geology, by V. Vellet; Dyke Rocks of Cape St. Martin, by J. D. T. Otto; Geology of the Klein Letaba Gold Mine, Sutherland Range, North-Eastern Transvaal, by B. F. Weilers; Petrographic Study of the Waterfall Gorge Profile at Insizwa, by D. Bruynzeel; Granite-Hornstone Contact at Slippers Bay, by J. R. McIver.

These articles it will be seen deal with geomorphology, petrology, sedimentation, ore deposits, and structural geology. Each article is well documented with maps and illustrations. The volume brings together much new material and a review of older knowledge of the geology of South Africa. It contains a lot of good reading.

Lectures on Rock Magnetism. By P. M. S. Blackett. Pp. 131. Weizmann Science Press, Jerusalem, 1956. Price, $5.00.

This book was reviewed in the August number of the Journal, Vol. 52, page 591, where the publisher was given as the Interscience Publishers, Inc., New York and London. This was an error, since the Interscience Publishers Inc. are only the distributors and the sole publisher is the Weizmann Science Press.

Economics of Atomic Energy. By Mary S. Goldring. Pp. 179. Philosophical Library, New York, 1957. Price, $6.00.

Miss Goldring discusses critically the growth of Britain's nuclear power, which so far has led the world. The book is divided into 3 parts. Part I deals with atomic factories, tools of industry, and the scale of investment. Part II, Atomic Power, considers the need for power, its cost, and the export market. Part III is on Atomic Investment. It includes the British Pattern, Atoms and Industry, Other Countries' Methods, and Britain's Atomic Future. An appendix gives civil expenditure on atomic energy in Britain, and the capital value of assets of the Atomic Energy Authority. At the beginning, following a brief discussion of the occurrences of uranium (without mentioning the Colorado Plateau!), the author describes in simple language the structure of the atom, and the radioactivity of uranium. The remainder of the book is devoted to the economics of atomic power plants. The book is written in simple language understandable to everyone.

Finding Fossil Man. By Robin Place. Pp. 126; figs. 46; pl. 63. Philosophical Library, New York, 1957. Price, $7.50.

The author intended this book for students in public schools, but it should serve even more for the general reader. Its 17 chapters take up, first animal families and the "family" of man. One is then led through the development and evolution

of the vertebrates—through fishes, birds, reptiles and mammals. The contributions of the mammals to man are pointed out, as are also the similarities between apes and man. Various types of skulls and jaws are pictured and considerable discussion is given to the finds of early fossil man. It is an interesting simple discussion of the evolution of man.

Old Stone Age, Nature and Art Series. By STEVAN CÉLÉBONOVIC. Commentary by Geoffrey Grigson. Pp. 96; pl. 72; size 9¼ × 12½. Philosophical Library, New York, 1957. Price, $10.00.

This volume follows a similar one, "The Living Rocks." The story of stone age man is vividly told by 72 large plates artistically and beautifully photographed by the author. One is given an understanding of how man lived, his conditions of climate and vegetation, and his associated beasts and birds, carved in stone. The plates portray man's early attempt at art and the tools with which he accomplished his carvings. Interwoven with the plates are some 27 pages of text by Geoffrey Grigson in which a poet-scientist guesses what passed in the minds of these stone-age men as drawn from his pictures, tools, and relics. It is an interesting book of archeology depicted by visual technique.

BOOKS RECEIVED

JAMES M. ALLEN AND JOHN W. SALISBURY

Poison on the Land. J. WENTWORTH DAY. Pp. 246. Philosophical Library, New York, 1957. Price, $6.00. *Present-day treatment of land by toxic farm chemicals is threatening to kill off many birds, animals, and fish; gives suggestions to preserve wild life by use of good modern fertilizers and insecticides.*

Economic Fictions, A Critique of Subjectivistic Economic Theory. PAUL K. CROSSER. Pp. 322. Philosophical Library, New York, 1957. Price, $4.75. *The rise, the climax, the anti-climax, and the anti-anticlimax of economic subjectivism; critiques of works of Menger, Wieser, Boehm-Bawerk, Clark, Jevons, Schumpter, Keynes, Spann, and others.*

Iron Ore Beneficiation. LAWRENCE A. ROE. Pp. 305; figs. 27. Minerals Publishing Co., Lake Bluff, Illinois, 1957. Price, $5.00. *History; sources and economics; minerals; washing, heavy media gravity, flotation, magnetic, pyrometallurgy, hydrometallurgy; agglomeration; research. A compact up-to-date treatment.*

Bibliographies, Reference and Source Works. Pp. 68. Acquistions Bulletin No. 4/5 (October–November, 1957). Kraus Periodicals Inc., New York, 1957. *List of recently acquired books, covering a wide range of the humanities and sciences.*

The Australian Mineral Industry—1956 Review. Pp. 226; figs. and charts 20; tbls. 298. Price, 12/–. Bureau of Mineral Resources, Geology and Geophysics, Melbourne, 1957. *Production and utilization of minerals for 1956.*

Annual Report of the Geological Survey Department for the Year Ended 31st December, 1956. Pp. 28; pl. 1; fig. 1; tbls. 7. Price, 2 sh. 6d. Bechuanaland Protectorate, Parow, 1957. *Activities of the geological survey during 1956. Provisional geological map of Bechuanaland included.*

Comité Spécial du Katanga: Rapports et Bilans de l'exercice 1956. Pp. 165; pls. 2. Bruxelles, 1957. *Report of work done and production of minerals and raw materials from the Congo during 1956.*

Carte Géologique de la Nouvelle-Calédonie—sheet 3: Hienghène-voh. André Arnould and Pierre Routheir. Pp. 70; figs. 3. Office de la Recherche Scientifique et Technique Outre-mer, Paris, 1957. *Geologic history, topographic evolution, stratigraphy, structure, petrology and mineral deposits of an area in western New Caledonia. Nickel, cobalt, iron, chrome, asbestos, talc, rutile, manganese and coal occurrence reported.*

Journal of the Institute of Polytechnics—Series G, Geoscience. Vols. 1, Nos. 1 and 2. Osaka City University, Osaka, Japan. *This relatively new journal entirely in English contains geochemical, geophysical, economic geology, petrology, sedimentation and paleontology papers.*

Structural Studies of the Snow Lake-Herb Lake Area, Herb Lake Mining Division, Manitoba. G. A. Russell. Pp. 33; pls. 3. Providence of Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 55–3. Winnipeg, 1957. *Mineral deposits associated with newly identified thrust block. Accompanying map and cross-sections. Scale: 2 inches equal 1 mile.*

Simposium Sobre Yacimientos de Petroleo y Gas. Tomo II. Asia y Oceania. Geological Occurrence of Oil and Gas in Australia. M. A. Condon. Pp. 25; figs. 2; tbls. 3. International Geological Congress, Mexico City, 1956. *Discussion of possible source areas for petroleum in Australia. To date one flowing well has been discovered.*

Annual Report for April 1, 1956 to March 31, 1957. J. W. Gruner and J. A. Knox. Pp. 51; tbls. 2. U. S. Atomic Energy Commission, Oak Ridge, Tennessee, 1957. *Mineralogy of the Ambrosia Lake uranium deposits of McKinley County, New Mexico. Solubility of U and V compounds in bicarbonate solutions of Na, Ca, and Mg in excess of CO_2. Experiments showing the improbability of the reduction and precipitation of uranous oxide from solution; by pyrite, marcasite or chalcopyrite at room temperature.*

Estudos, Notas e Trabalhos do Serviço de Fomento Mineiro. Serviços Geológicos da Portuguesa. Vol. XII; Fascs. 1–2. Pp. 165; pls. 16; figs. 13; tbls. 5. 1957. *Various short articles on treatment of iron ores. Geological report and map on marble producing area in central Portugal.*

Bulletin of The Geological Institutions of the University of Uppsala. Vol. XXXVII, parts 3–4. Pp. 265; pls. 15; figs. 46; tbls. 40. Uppsala, 1957. *Comprehensive description of middle Ordovician ostracodes of central and southern Sweden. 62 species are described including 23 new species.*

Annual Report of the Geological Survey Dept. for the Year Ended 31st December, 1956. Pp. 39; tbls. 17. Price, 2 sh. Uganda Protectorate, Entebbe, 1957. *Report of work done by the department during 1956. Wolframite was the most important mineral export accounting for 164.24 long tons.*

Geology of the West Coast of Tasmania, Part III: Porphyroid Metasomatism. J. Bradley. Pp. 26; pls. 4; figs. 23. University of Tasmania Dept. of Geology, Hobart, 1957. *Petrology, petrogenesis of quartz and feldspar porphyries. Feldspar porphyries considered to have been formed by feldspathization of spillitic lavas during progressive metamorphism, quartz porphyries formed during a subsequent regressive phase of metamorphism.*

Geology of the Clifton Forge Iron District, Virginia. F. G. Lesure. Pp. 127; pls. 22; figs. 12; tbls. 16. Virginia Polytechnic Institute Bull. Vol. L, No. 7, Blacksburg, 1957. *Stratigraphy, structure, geomorphology and economic geology of an Ordovician to Devonian terrain in western Virginia. Description of deposits, ore controls, origin of secondary iron ores.*

Recueil des Travaux de L'Institut de Géologie "Jovan Žujović," Tome VIII. Pp. 391; pls. 41; figs. 81; tbls. 15. Beograd, Yugoslavia, 1955. *All 28 articles have English, French, or German abstracts.*

Geologija, Transactions and Reports. Pp. 269; pls. 37; figs. 40; tbls. 40. Geological Survey of P. R. Slovenia, Ljubljana, 1955. *Papers on mine geology, areal geology, stratigraphy, paleontology, mineralogy and ore genesis. In Yugoslavian. Summaries in English.*

Departamento Nacional de Produção Mineral—Rio de Janeiro, Brazil, 1955–56.

Bol. 96. Geologia da Fôlha de Tubarão, Estado de Santa Catarina. HANNFRIT PUTZER. Pp. 94; pls. 17; tbls. 9. *First geologic map of Sheet Tubarão, which contains the greater part of Brazil's coal reserves. Reserves estimated. Geologic map, scale 1:250,000.*

Bol. 98. Higiene das Minas Asbestose. C. M. TEIXEIRA and M. MOREIRA. Pp. 61; pls. 16; tbls. 3.

Bol. 99. Pp. 84; pls. 6; figs.; tbls. 18. *Two articles by D. Guimarães and one by W. Belezkij concerning mineral deposits in the municipality of São João Del Rei, Minas Gerais.*

Monograph XIII. Geologia e Petrlogia do Arquipélago de Fernando de Noronha. FERNANDO F. F. DE ALMEIDA. Pp. 181; pls. 46; figs. 34; tbls. 30. *Geologic map, scale 1 :15,000.*

British Columbia Department of Mines—Victoria, 1957.

Mine Electrical Installations. L. WARDMAN. Pp. 15. *Brief descriptions of types of electrical installations in lode, placer, coal mines and quarries in B.C.*

Annual Report for the Year Ended 31st December, 1956. *Production statistics for B.C. mines during 1956. Resumé of the activities of the mines branch.*

Geological, Mining and Metallurgical Society of India—Calcutta, 1956–57.

Bull. 16. A Plan for Establishing Aluminum Industry in Central India Near Rihand Dam, Uttar Pradesh. B. K. MAHENDRA. Pp. 32; figs. 9. *Aluminum, coal, limestone, hydro-electric power, and efficient railway service are found near Rihand Dam.*

Bull. 18. On Certain Mines, Geological and Mining Institutions and Factories in Japan. B. C. ROY. Pp. 32; figs. 2; tbls. 19.

Indiana Geological Survey—Bloomington, 1957.

Directory No. 5. Directory of Coal Producers in Indiana. C. E. WIER. Pp. 100; pl. 1. figs. 3; tbl. 1. Price, $.75. *Includes sections on characteristics, nomenclature, and correlation of Indiana coals.*

Bull. 10. A Middle Pennsylvanian Foraminiferal Fauna from Dubois County, Indiana. JOSEPH ST. JEAN, JR. Pp. 66; pls. 5; figs. 3; tbl. 1. Price, $1.75. *Three new species of Endothyra and one of Endothyranella are described.*

Missouri Geological Survey—Rolla, 1956–57.

Rept. of Invest. 21. Northeast Missouri's Oil Possibilities Improve. EARL MCCRACKEN. Pp. 2; figs. 3; tbls. 2.

Information Circ. 13. Asphaltic Rocks in Western Missouri. W. V. SEARIGHT. Pp. 26; pl. 1; tbls. 20. *Asphaltic rocks in Western Missouri are not oil indicators. The oil has migrated up the dip of the beds for considerable distances to the outcrop zone.*

Montana Bureau of Mines and Geology—Butte, 1957.

Bull. 8. Mines and Mineral Deposits Missoula and Ravalli Counties, Montana. U. M. SAHINEN. Pp. 63; pls. 10; figs. 10; tbls. 9. Price, $1.00. *An inventory of the present status of the mineral industry of this area.*

Misc. Contribution 15. Some Occurrences of Uranium and Florium in Montana. L. D. JARRARD. Pp. 90; pls. 5; tbls. 2. Price, $1.00. *Supplements Information Circ. 6 (Prospecting for Uranium in Montana) with more detail concerning the state's resources and data on more recent discoveries.*

Information Circ. 18. Expandable Shale in the Great Falls Area, Montana. U. M. SAHINEN. Pp. 16; pls. 2; tbls. 4. *Suitable material exists for the establishment of a lightweight aggregate industry.*

Norges Geologiske Undersökelse—Oslo, 1957.

The Copper Deposits of the Birtavarre District, Troms, Northern Norway. F. M. VOKES. Pp. 236; pls. 13; figs. 67. *Location, character, size and geologic setting of small chalcopyrite-pyrite deposits. Paragenesis, trace element distribution, wall rock alteration and origin of the ores are discussed. At present deposits are too low grade and too small to be considered economic.*

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Province of Quebec Department of Mines—1957.

Geological Rept. 69. Coaticook-Malvina Area, Electoral Districts of Stanstead and Compton. H. C. COOKE. Pp. 36; figs. 7. *Geological map 1:63,360. Areal geology of terrain in southern Quebec underlain by Ordovician and Silurian Beds and intruded by Devonian granite.*

Geological Rept. 72. Southwest Part of Lesueur Township, Electoral District of Abitibi-East. R. B. GRAHAM. Pp. 26; fig. 1; pls. 2. Geological map 1:12,000. *Areal geology of Precambrian metamorphic igneous and volcanic terrain in N. W. Quebec. Gold, silver, zinc and lead mineralization has been found in the area.*

U. S. Geological Survey—Washington, D. C., 1957.

Prof. Paper 260-S. Seismic-Refraction Studies of Eniwetok Atoll. R. W. RAITT. Pp. 685–698; figs. 14. Price, 20 cts. *Study of seismic-wave velocities down to the Mohorovicic discontinuity.*

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Bull. 1045-C. Core Logs from Soda Lake San Bernardino County California. SIEGFRIED MUESSIG, G. N. WHITE, and F. M. BYERS, JR. Pp. 81–96; pl. 1; fig. 1. Price, 50 cts.

Bull. 1059-C. Selected Annotated Bibliography of the Geology of Sandstone-type Uranium Deposits in the United States. R. E. MELIN. Pp. 59–175; fig. 1. Price, 35 cts.

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SOCIETY OF ECONOMIC GEOLOGISTS

MEETING

New York City, February 17–20, 1958

The next meeting of the Society of Economic Geologists will be held in New York City, on February 17–20, 1958, in conjunction with the Annual Meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers. Headquarters and place of scientific sessions will be at the Statler Hotel.

The following technical sessions will be presented at the time and place indicated, under the joint sponsorship of the SEG and AIME.

Copper Mineralization and Regional Structure in Arizona, New Mexico and Sonora

Geology—SEG

Monday, February 17, 2:30–5:30 P.M. West Room, Statler Hotel

Chairmen: W. C. Lacy and K. Cochran.

Relation of Mining Districts to Regional Tectonics, with Special Reference to Southern Arizona and Southwestern New Mexico: S. E. Jerome and D. R. Cook.

Lineament Tectonics and Some Ore Districts of the Southwest: Evans B. Mayo.

Tectonic Control of Mineral Belts in the Southwestern Colorado Metallogenic Province: John W. Gabelman.

Notes on Mineralized Breccia Pipes: Reno Sales and Roland Mulchay.

The Geology and Ore Deposits and Prospects in the Tucson, Arizona, Area: H. A. Schmitt.

Geology of Titanium

Geology—Industrial Minerals—SEG

Tuesday, February 18, 9:00 A.M.–12:00 NOON. Georgian Room, Statler Hotel

Chairmen: Wm. H. Callahan and Meredith Johnson.

Lac Tio Ilmenite Deposit: Dr. E. O. Dearden.

Sand Deposits of Titanium Minerals: J. L. Gillson.

Exploration Methods and Evaluation of Sand Type Deposits: Frank McKinley.

The Titanium Sands of Southern New Jersey: Frank J. Markewicz, Daniel G. Parillo, Meredith E. Johnson.

Titanium Sand Deposits in Australia and West Africa, Louis Moyd.

A Society luncheon will be held on Thursday, February 20, 12:30 P.M., in the Grand Ball Room, Statler Hotel. Tickets are $4.75. If you have not made reservations through the AIME, please purchase your ticket for the luncheon when you register. Non-members of the Society are welcome. Bar service will be available in the Grand Ball Room prior to the luncheon for the convenience of any who may wish to use it.

SCIENTIFIC NOTES AND NEWS

W. S. McCann has been appointed by the United Nations, under the Technical Assistance Administration, to advise the Venezuelan Government on the exploration and development of the bauxite deposits in that country.

A. R. Kinkel, Jr., of the U. S. Geological Survey, has returned to Washington, D. C., from a two month's study of base metal and iron deposits in Turkey. This study was made at the request of the International Cooperation Administration.

D. A. Gallagher, U. S. Geological Survey, has returned to Menlo Park, California, after completing a two and a half month assignment as Geological Advisor to the Korean Government, the Geological Survey of Korea, and the Director, ICA/U. S. Operations Mission at Seoul.

G. W. Morey has retired from the Geophysical Laboratory and is now with the Geochemistry and Petrology Branch at the U. S. Geological Survey with a laboratory at the Naval Gun Factory. He brought his high pressure equipment with him and is carrying on the same experimental program as before.

R. A. MacKay returned to England recently from Rhodesia and Persia and left again on a short visit to Portugal.

A. C. M. McKinlay of the Geological Survey Department, Tanganyika, is in the United Kingdom until March, 1958.

H. C. Scholtz has left Baghdad, Iraq, and is now working with Geophysical Surveys, Ltd., Johannesburg, Transvaal.

B. Scott has been promoted to assistant chief geologist, Electrolytic Zinc Co. of Australasia, Ltd., Rosebery, Tasmania.

Paul Gast of the Lamont Research Institute at Columbia University conducted a seminar in Isotope Geology at the University of Minnesota, Minneapolis, during the autumn term of the current academic year.

D. L. Marksbury has accepted a position as staff geologist at Kennecott Copper Corporation's Ray Mines Division in Ray, Arizona.

Gerald Fitzgerald, chief topographic engineer of the U. S. Geological Survey, retired recently after 40 years with the Survey. He is replaced by George D. Whitmore, former deputy chief topographic engineer.

H. L. Hartman has been named professor and head of the Department of Mining at The Pennsylvania State University. He replaces Arnold W. Asman who resigned recently. (A correction.)

R. A. Hardy, Jr., was recently named as Assistant Secretary of the Interior for Mineral Resources. Mr. Hardy had been general manager of Manganese Inc. in Henderson, Nev., since February, 1956. In his new post, he will supervise the Bureau of Mines, the U. S. Geological Survey, the Defense Minerals Exploration Administration, the Office of Mineral Mobilization, and the Division of Geography of the Interior Department.

P. L. CLOKE is now a research fellow in the department of geology of Harvard University, Cambridge, Mass., where he has started a research program to try to solve the problem of sulfide ore transport. Previously he was with The Anaconda Co. as a research geologist.

H. R. COOKE, JR., is now a consulting mining geologist in Reno, Nevada. Previously he was senior exploration geologist for Martin Sykes & Associates in South America.

S. P. BROWN has joined St. Lawrence University, Canton, N. Y., as assistant professor of geology. Formerly he was geologist for the St. Joseph Lead Co., Balmat, N. Y.

E. H. AHRENS, JR., is now field geologist in charge of the Noranda, Quebec, office of The Anaconda Company. He previously was assistant mines geologist for the company in Butte, Montana.

F. N. EARLL, recently geologist for the Western Consulting Service, Salt Lake City, Utah, is now assistant professor of geology at the Montana School of Mines, Butte.

ERWIN ROSE is taking a special course on photogeology at the International Training Center for Aerial Survey in Holland. Previously he worked as a mining exploration geologist in Peru and Venezuela.

P. C. DELAITRE has terminated his position as mining consultant for the Ministerio de Minas, Venezuela, and is at present employed as a U.N. Mineral Resources Expert for the U.N. Technical Assistance Administration, New York. Next, he expects to go to Jordan for the U.N.

A. J. HALEY has been appointed director, mineral research and development department of the Great Northern Railway Co., with headquarters at Seattle and St. Paul.

R. C. BARKLEY is now employed as a geologist in the uranium exploration division of Kerr-McGee Oil Industries Inc., Albuquerque, N. M. Previously he was a geologist with the U. S. Atomic Energy Commission at Hot Springs, South Dakota.

R. LEE-ASTON is now a member of the faculty of University of Chattanooga, Evening College, Chattanooga, Tenn., where he is an instructor in mining geology.

A. M. SHORT is now a private consultant in Golden, Colorado. Formerly he was economic geologist for the Directorate of Petroleum and Mineral Affairs of the Saudi Arabian Government.

A. B. EMERY died at Salisbury, Southern Rhodesia on July 26, 1957, at the age of 82.

The NSF has just announced it will again support a Summer Institute in Geology for College Teachers in 1958. The institute will be held at the Department of Geology, University of Illinois, Urbana, from June 16 to August 9, 1958. The same financial provisions will be in effect: $600 stipend; $120 allowance for each dependent up to 4, and a travel allowance at the rate of four cents per mile for a single round trip up to a maximum of $80. Dependency allowances are paid whether or not dependents accompany participants.

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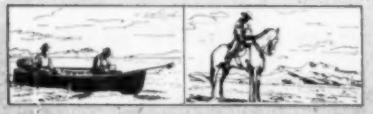

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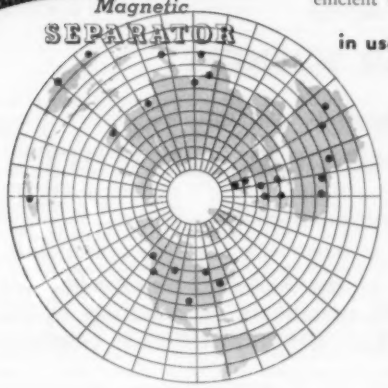

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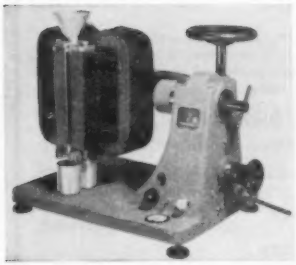

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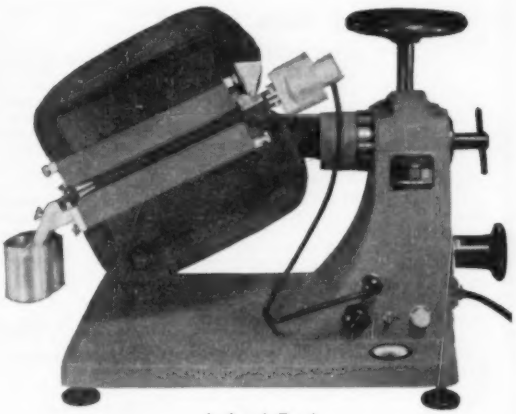

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